DESIGN AND MODELLING OF VACUUM EXPERIMENTAL SET-UPS

A thesis

submitted by

TRILOCHAN PENTHIA

Roll No.212ME5328

In the partial fulfillment for
the award of the degree

of

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DEPARTMENT OF MECHANICAL ENGINEERING
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ROURKELA, ODISHA, INDIA-769008
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MASTER OF TECHNOLOGY
in
CRYOGENICS AND VACUUM TECHNOLOGY

Under the supervision
of
Prof. Sunil Kumar Sarangi

NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA, ODISHA, INDIA-769008
May 2014

National Institute of Technology
Rourkela, Odisha, India – 769008

CERTIFICATE

This is to certify that the thesis entitled, **"DESIGN AND MODELLING OF VACUUM EXPERIMENTAL SET-UPS"** submitted by **TRILOCHAN PENTHIA (Roll No: 212ME5328)** in partial fulfillment of the award of **Master of Technology** degree in **Electrical Engineering** with specialization in **Cryogenics and Vacuum Technology** during the period **2013-14** at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or diploma.

Project Supervisor
Prof. Sunil Ku. Sarangi, Director
National Institute of Technology, Rourkela

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Place: Rourkela

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212ME5328

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CHAPTER 3

DESIGN AND DESCRIPTION OF EXPERIMENTAL SET-UPS PROPOSED.

ABSTRACT

This thesis deals with study, modelling and designing of some laboratory apparatus in Cryogenics Engineering and Vacuum Technology field. The project is totally educational oriented. Project's aim is to give a clear idea about vacuum technology and modelling of such vacuum experimental set-ups which can serve as the laboratory experiments for both undergraduate and post graduate students.

This project work is broadly classified into three parts:--

(i) Study, selection techniques and designing of some vacuum components.

(ii) Modelling and operation of vacuum experimental set-ups.

(iii) Making bills of materials for the proposed experimental se-ups.

The experiments to be done are namely;

(i) Study & Calculation of pumping speed of diffusion pump.

(ii) Study & Calculation of pumping speed of roots pump.

(iii) Study & Calculation of pumping speed of vacuum ejector pump.

(iv) Study & Calculation of pumping speed of cryopump.

(v) Calibration of vacuum gauges using primary gauges.

(vi) Study and calculation of boil-off rate & heat transfer characteristics of vacuum insulation.

Design of various components is done like vacuum chambers, thickness and length of pipe lines etc. So many calculations are done like calculation of pumping speed & flow rate of rotary pump, diffusion pump, roots pump and cryopump. Also calculation of boil-off rate of LN_2 in vacuum insulation experiments is carried out. Constant volume method and constant pressure methods are used for pumping speed calculation. Vacuum insulation is studied in three ways one is with plain vacuum, second is with powder vacuum and the third one is with multilayer insulation.

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CHAPTER-01

INTRODUCTION

This project works focused mainly on generation of vacuum of different levels and to reduce the heater transfer phenomena of cryogenics system (i.e. by vacuum insulations). Different vacuum level means like low vacuum (1000mbar to 1 mbar), medium vacuum (1 mbar to 10^{-03}mbar), high vacuum (10^{-03}mbar to 10^{-07}mbar) and ultrahigh vacuum (more than 10^{-07}mbar). Generation of vacuum requires the vacuum pumps and pressure measuring devices.

For any vacuum system, vacuum pumps are unavoidable and main parts of the system.

So ultimately, the project works are based on the different types of vacuum pumps.

There are different types of vacuum pumps having different pumping speed are available in market. The names of some vacuum pumps are namely;

(i) Rotary pump(Ultimate pressure: upto $1x10^{-03}$mbar)

(ii) Diffusion pump(upto $1x10^{-06}$mbar)

(iii) Roots pump/roots blower(upto $1x10^{-04}$mbar)

(iv) Cryopump(upto $1x10^{-12}$mbar)

(v) Ejector pump(upto 50 mbar)

(vi) Turbomolecular pump (upto $1x10^{-09}$mbar) and

(vii) Sorption pumps (upto $1x10^{-04}$mbar) etc.

Accordingly, the proposed experimental set-ups are namely;

(a) Diffusion pumping system

(b) Roots pumping system

(c) Cryopumping system

(d) Ejector pumping system

(e) Calibration of vacuum gauges using primary gauge

(f) Vacuum insulation.

The tasks of this project related to experimental set-ups of vacuum pumps are as follows:

- Generation of vacuum.
- Pressure of measurement w.r.t time.
- Calculation pumping speed of pumps and
- Plotting graphs between pumping speed (S), flow rate (Q), pressure (P), time (t) etc. (like P vs t, S vs P etc.)

Vacuum systems are used most commonly in laboratory scale cryostats, space simulations, superconducting magnet systems etc.

The objectives of vacuum systems are:-

- To attain the desired level of vacuum in a reasonable time.
- To maintain trouble free vacuum for a desired length of time.
- Easy operation and servicing.
- Minimum down time.
- To pump out the high vacuum insulation spaces in the cryostat and transfer tube
- To set up a pressure gradient along a pumping line so that the flow of cryogen through the cryostat can be controlled.
- To pump out an exchange gas.
- Cost effective.

CHAPTER-02

Cryogenics and vacuum technology: An Overview

2.1 What is Cryogenics?

A body or environment having temperature less than -150°C or 123K is called cryogenics temperature.

2.2 What is Vacuum?

Any given space having molecular density less than $2.5x10^{19}$molecules per cubic centimeter is said to be under "**Vacuum**" conditions. In another word, a space containing gas at a pressure below the atmospheric pressure is called vacuum.

2.3 Ideal Vacuum?

A space is said to be ideal if it is totally devoid of all matter.

2.4 Vacuum Technology?

The technology dealing with the production of such reduced-pressure or vacuum environments using different scientific concepts is known as "Vacuum Technology".

2.5 Units of Vacuum?

Vacuum is basically measured in pressure units. Its dimensional formula is $[L]^{-1}$ $[M]$ $[T]^{-2}$, where L, M, and T represent the base units of length, mass and time respectively.

As vacuum is concern with gas concept, so it obeys all the concepts of gas like laws, principles, theories, phenomena etc. of gases.

2.6 Ranges of Vacuum

Low vacuum or rough vacuum	760 Torr to 1 Torr
Medium Vacuum	1 Torr to 10^{-3} Torr
High vacuum	10^{-3} Torr to 10^{-7}Torr
Ultra high vacuum (UHV)	$>10^{-7}$Torr

2.7 The key terms related to vacuum technology:

- Pumps
- Valves
- Gauges
- Seals

These are very important elements in vacuum systems. Without pumps vacuum can't be produced. To measure the vacuum, gauges are mandatory. The role of valves and seals is to keep vacuum remains constant.

2.8 Types of Vacuum pumps:

(i) Positive displacement vacuum pumps:

In this type of vacuum pumps the gas is displaced by varying the volume of the vacuum chamber at a regular interval and is exhausted directly to the atmospheric pressure. Rotary pumps (single stage and double stage) and roots pump/roots blower pumps comes under this category.

(ii) Ejector pumps:

In this pump the pumped gas is entrained in a jet of the working medium. i.e. it is works on the principle of ventury effect.

Diffusion pump and other simple ejector pumps are falls under this category of pump.

(iii) Sorption pump:

Here the gas is pumped by either physi-sorption or chemi-sorption onto the surface of sorbing materials, such as activated charcoal, molecular sieves, titanium surface and other getter materials.

(iv) Molecular vacuum pumps:

In this pump, the pumped gas molecules are imparted an additional speed in a specified direction. Turbomolecular pump falls under this category.

(v) Ion pumps:

These pumps work on the principle of ionization of the gas and further directing the ions towards the neutral surfaces where ions are adsorbed or trapped.

There are different types of ion pumps; such as evaporation ion pumps and sputter ion pumps depending on the mode of generating the adsorbing agents.

(vi) Cryogenic vacuum pump:

In this pump cryogenic technique is used. Here the gases and vapors are frozen in low vapor pressure species in refrigerated cryopanels. Cryo-condensation and cryo-sorption pumps come under this category.

2.9 Vacuum measuring devices:

Pressure measuring devices can be broadly classified into following two types

(a) Total pressure gauges and

(b) Partial pressure gauges

Total pressure gauge again divided into types.

(i) Direct gauges (Primary gauges)

(ii) Indirect gauges (Secondary gauges)

Direct gauges:-

- Mechanical gauges fall under this category.

e.g. Bourdon, diaphragm, liquid manometers and McLeod gauge.

- **Indirect gauges:-**

  Thermal conductivity gauges: Here the kinetic theory of gases predicts the dependence of the thermal conductivity of a gas on its pressure. e.g. Thermocouple and Pirani gauges.

  Ionization gauges:

  (i) Hot cathode gauges: BAG, Orbitron, Magnetron etc.

  (ii) Cold cathode gauges: Penning, Inverted magnetron etc.

Partial pressure gauges:-

Mass spectrometer, quadrupole and monopole mass spectrometers.

2.10 Application of Cryogenics and vacuum technology:

- nuclear research
- space research
- metallurgy
- thin film coating
- freeze drying
- Food Processing
- Plastics Manufacturing
- Power transmission
- Nano manufacturing etc.

CHAPTER-03

3.1 Designs, methods and selection techniques of materials, vacuum & non-vacuum components:

(i) Vacuum chambers.

(ii) Flow meters

(iii) Vacuum pumps

3.1.1 Vacuum Chambers:-

Designing a vacuum chamber means defining the boundary conditions (inner and outer envelopes, operational constraints, etc.), vacuum sealing and choosing the materials etc.

The circumferential stress under external pressure *p* is simply:

$$\sigma_\theta = \frac{pR}{t}$$

Where, R= radius of circular pipe

t= thickness of circular pipe.

If the tube is closed and subjected to an axial force *F*, then the axial stress is

$$\sigma_z = \frac{pR}{t} + \frac{F}{2\pi Rt}$$

And the Von Misses equivalent stress to be compared to the material maximum allowable stress is

$$\sigma_e = \frac{1}{2}\left[3\left(\frac{pR}{t}\right)^2 + \left(\frac{F}{\pi Rt}\right)^2\right]^{\frac{1}{2}}$$

The buckling pressure (p_{cr}) can also be computed through analytical formulas, depending upon the geometrical parameters of the tube and the Young's modulus of the material. The most conservative one is for an infinite length of the tube:

$$p_{cr} = \frac{0.25E}{1-\nu^2}\left(\frac{t}{R}\right)^3$$

Where, ν = poison's ratio

E= Young's modulus of the material

$1-\nu^2$ = generally approximated by 0.9

3.1.2 Selection of materials for vacuum systems:-

The selections of materials are carried out to meet following requirements:-

- Low saturated vapour pressure at room temperature.
- High vacuum sealing at a minimum materials thickness.
- Least attainable outgassing in vacuum and ease of degassing

Most metal have very low vapour pressure however some metals and alloy have high vapour pressure. So, metals and alloys having high vapour pressure can't be used for ultra-high vacuum applications.

For instance, alloy which contains metals like zinc, cadmium, sulphur, selenium, lead etc. have high vapour pressure.

Metals having very low vapour pressure are: stainless steel, aluminum, mild steel, austenite steel etc.

3.1.3 vacuum Selection of pumps:

As we know, in market vacuum pumps having different pumping speeds are available. So, our task is to find out the suitable pump having desired pumping speed range. We have a known volume and maximum time to be taken to evacuate the vacuum chamber of known volume.

The question arise here is how will we know the pumping speed for a known volume?

The formula for finding out the pumping speed of a pump to evacuate a chamber of known volume within a particular time is given by;

$$\frac{-dp}{dt} = \frac{S}{V} * P$$

$$\Rightarrow \int_{P_{atm}}^{p} \frac{dp}{p} = -\frac{S}{V}\int_{0}^{t} dt$$

$$\Rightarrow \ln\left(\frac{P}{P_{atm}}\right) = -\frac{S}{V} * t$$

$$\Rightarrow S = \frac{V}{t}\ln\left(\frac{P_{atm}}{P}\right)$$

$$\Rightarrow S = \frac{V}{t}\ln(K)$$

Where, S=pumping speed (Unit: liters/sec)

P_{atm}=Atmospheric pressure (mbar), 1013 mbar

P= desired pressure or ultimate pressure (mbar)

V=Volume of the chamber, (liters).

t= time taken to evacuate volume of 'V' from pressure P_{atm} to P, (second)

K=compression ratio

3.1.4 Selection criteria for pump systems are:-

- Pumping speed
- Operating pressure
- Process conditions
- Characteristics of the media
- Standards and regulations which depend on the area of application and the produced products.

3.1.5 Selection of flow meter:-

The flow rate or throughput of a flow meter can be determined by following general formulae;

For known S and P

$$Q=S*P$$

Where, Q= flow rate (mbar-l/s)

S=pumping speed (l/s)

P= pressure (mbar)

In sccm (standard cubic centimeter):-

Flow rate= $S*P*60$ sccm

So, if we have a pressure range i.e. maximum pressure and ultimate vacuum pressure of pump then we will find out the flow meter range.

For instance;

Let us consider for diffusion pump (DP). We have pressure range: 10^{-03}mbar to 10^{-06}mbar and suppose the pumping speed of DP is 280 l/s.

Now the flow rate or throughput varies

10^{-06}x280 mbar-l/s to 10^{-02}x280 mbar-l/s

=10^{-06}x10^{-03}x280x10^{03}x60 sccm to 10^{-03}x10^{-03}x280x10^{03}x60 sccm

=0.02 sccm to 16.8 sccm

So, we need a flow meter range of 0-20 sccm to measure the flow rate of pump.

3.1.6 Design Considerations of vacuum pumping systems:-

- Selection of vacuum pump of adequate capacity.
- Selection of matching mechanical/rotary pumps.
- Suitable interconnections.
- Air admittance facilities.
- Provision for measuring pressure at various stages.
- Protection against failure.
- Economic considerations.
- Minimum time at which the chamber will be evacuated.

3.1.7 Methods used for pumping speed calculation of vacuum pumps:-

Pumping speed can be calculated in two ways:

a) Constant pressure method.

b) Constant volume method.

3.1.7.1 Constant pressure method:-

Formula;

$$S = \frac{Q}{P}$$

Where

S=Pumping speed of diffusion pump (litrs/sec.)

Q=Flow rate (mbar-litrs/s)

P=Pressure of vac. chamber (mbar).

Constant pressure method can be done by either using a flow meter or a mercury pellet arrangement techniques.

3.1.7.2 Constant pressure method using a flow meter:-

(i) In the experiment first evacuate the vessel upto 10^{-6}mbar.

(ii) Air is admitted through a capillary tube-flow meter arrangement via needle valve such that chamber is being evacuated (refer **Fig-1, Fig-4 & Fig-10)**.

(iii) The needle valve is adjusted until the pressure indicated by the gauge is constant.

(iv) Now observation will be started by observing the pressure (P) and flow rate (Q) at a particular time interval Δt .

(v) Then calculate the pumping speed 'S' for each observation by using the above formula.

Tabulation-1

Sl. No	Time (second)	Press.; P (mbar)	Flow rate; Q (mb-L/s)	S=Q/P (L/s)
1				
.				
n				

3.1.7.3 Constant pressure method using calibrated mercury & glass capillary tube arrangement:

(i) This technique is same as the constant pressure method using flow meter.

(ii) A mercury glass tube-capillary glass tube connected instead of capillary tube-flow meter arrangement (refer **Fig-11)**.

(iii) Air is admitted through the calibrated mercury capillary tube via the needle valve such that the chamber is being evacuated.

(iv) The needle valve is adjusted until the pressure the pressure indicated by the appropriate gauge (penning gauge) is constant.

(v) The volume of air 'V' pumped out of the capillary tube in time 't' is given by the movement of mercury pellet in the capillary tube.

(vi) Now, pumping speed can be given as

$$S = \frac{Q}{P}$$

$$= \frac{V * P_1}{P * t}$$

$$= \frac{P_1}{P} * \frac{\prod r^2 L}{t}$$

Where,

P_1= Atmospheric press.

r= radius of capillary tube.

L=the distance by which the mercury level was displaced during time't'.

Tabulation-2

Sl. No	Time;t (in second)	Penning gauge reading(mbar)	Displacement of mercury level; L (mm)	S(l/s)
1				
.				
n				

3.1.7.4 Constant volume method:-

(i) Close the needle valve-capillary tube arrangement.

(ii) When pressure reaches to 10^{-2}mbar, start the observation at a certain time interval read down the corresponding pressure reading (by stop watch or mobile timer).

(iii) So, the pumping speed can be given as

$$S = 2.303 \frac{V}{\Delta t} \log\left(\frac{P_1}{P_2}\right)$$

Where

V=volume of chamber

Δt =time taken by the pressure decreases from P_1 to P_2.

Tabulation-3

No. of observation	Time, t(s)	Pressure(mbar)	S(l/s)
1			
.			
n			

3.2 Diffusion pumping system:-

This pumping system involves followings main components:-

(i) A diffusion pump

(ii) A rotary pump

(iii) A vacuum chamber

(iv) Two pirani gauges and one penning gauge.

(v) LN_2 Trap & baffles

(vi) Oil(DC704) bath

(vii) Water chiller

(viii) Flow meter and Display units etc.

Schematic diagram of diffusion pumping system:-

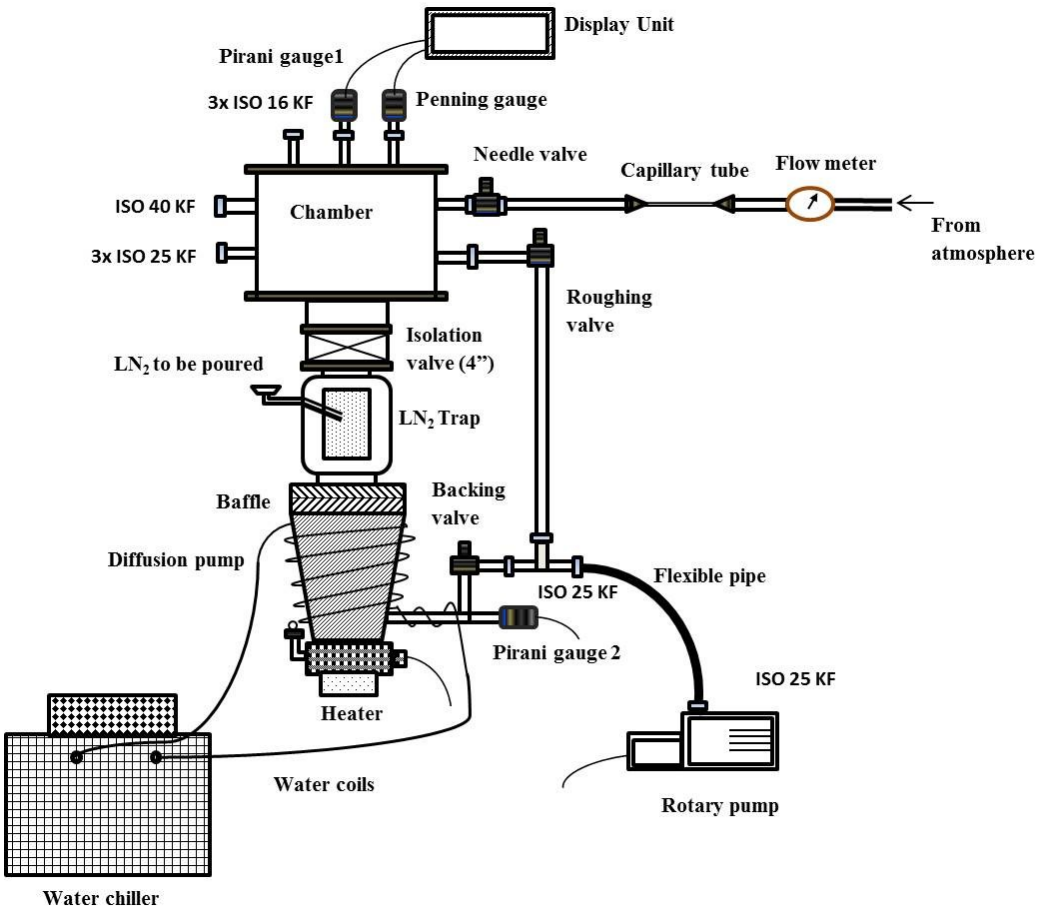


Fig-1: Experimental set-up of diffusion pumping system

Description and operation of the experimental set-up:-

The schematic diagram of diffusion pumping system is given in **Fig-1.**

Generally, diffusion pumping system generates vacuum upto 10^{-06}mbar. To cover this much of vacuum ranges two types of pressure measuring devices used. One is pirani gauge (1 mbar to 10^{-03}mbar) and the second is penning gauge (10^{-02}mbar to 10^{-06}mbar).

Aim of the diffusion pumping system is to evacuate the vacuum chamber upto vacuum 10^{-06}mbar. It involves valves, connecting pipes, pressure gauges, display unit, a flow meter, heating unit (heater), cooling unit (water chiller), capillary tube etc. as shown in the Fig 1. The volume of chamber is 20 liters. The specification of different components is given in the **Table-5** and **Table-6,** in **Chapter-4.** As diffusion pump alone can't run alone unless its foreline pressure is greater than 0.5Torr or order of 10^{-1}mbar. So, DP needs a backing pump i.e. rotary pump. Water chiller maintains the temperature of cooling coil between 15-25 °C.

As it is seen that 99.9% of pumping out process of diffusion pumping system performed by rotary pump. Remaining 0.1% pumps out by diffusion pump itself.

There is an arrangement of needle valve-capillary tube-flow meter (in **Fig-1**), which helps to calculate the pumping speed of diffusion pump. To calculate pumping speed two methods can be used; (i) Constant volume method and (ii) Constant pressure method. Details of methods described in **section 3.1.7.**

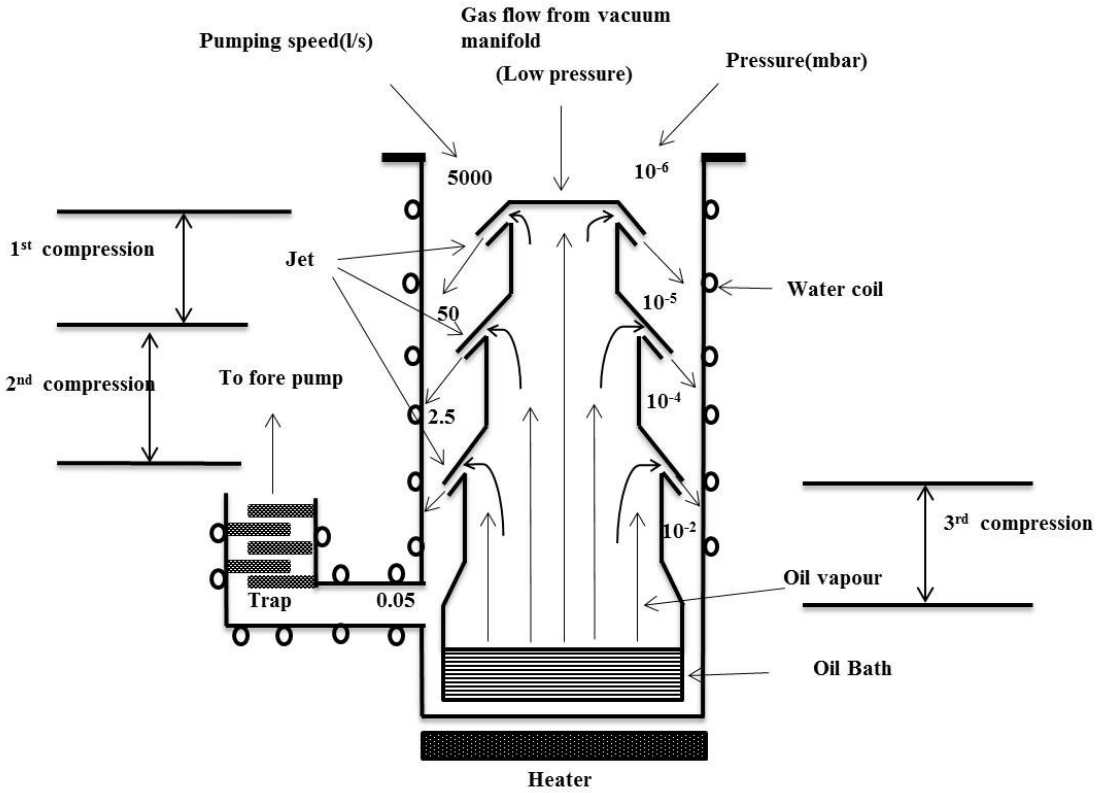
During the operation the backing valve remains opened and roughing valve closed. Main isolation valve is used to isolate the main chamber from the system when required. Roughing valve is used to pump the vacuum chamber separately by rotary pump. So, first the roughing operation will perform by closing both backing valve and isolation valve. When it reaches upto 10^{-1} to 10^{-2} mbar, the backing operation will be performed till the maximum vacuum achieved. During backing operation, you mustn't open the isolation valve unless the pressure reading of Pirani gauge2 reaches upto 10^{-2}mbar.

To increase the conductance, the connecting pipe should have shorter length and higher diameter. As pipe conductance is reciprocal of resistance.

3.2.1 Diffusion pump(DP):

In a diffusion pump a suitable liquid is boiled and the high energy molecules of the vapour are directed as a jet downward where they are condensed to a liquid again. The molecules of the gas in the chamber being evacuated reach the jet area by diffusion (hence the name diffusion pumps). The high energy molecules in the downward jet of the pump fluid transfer part of their momentum to the diffusing molecules, which thereby acquire a velocity towards the exit and are thrown out.

The construction of oil diffusion pumps differs from one another. A schematic drawing of an oil diffusion pump is shown in **Fig- 2**.



(**Fig- 2**: pumping mechanism of 3 stage oil diffusion pump. The numbers on the left-hand side of the three sets of jets, indicate the increasing pumping speed (l/s) from the 1st (bottom) to the 3rd (top) stage. On the right-hand side the decrease in pressure (mar) with pumping stage is shown. An oil baffle would be present at the intake of the pump in order to reduce the streaming of oil vapor into the vacuum manifold.)

Traps and baffles play an important role in generation of very high vacuum. Function of baffle is to block the oil vapour flowing through it. To keep the oil vapor within the confines of the pump, an oil trap needs to be provided on top of it. These oil traps are designed so that there is no optical connection between the pump and the vacuum chamber. In this way the back streaming of oil is reduced without affecting the gas conductivity of the vacuum line. Two types of traps are commonly used; Liquid nitrogen and Thermo-electric (Peltier effect) cooled baffles. Functions of trap are it traps or adsorb the air particles on the surface of it. Because it's surface maintains temperature of 77K. So its traps air particles except non condensable gases like Hydrogen, Neon, Argon, Helium etc.

The physical specification of diffusion pump (size 4"):-

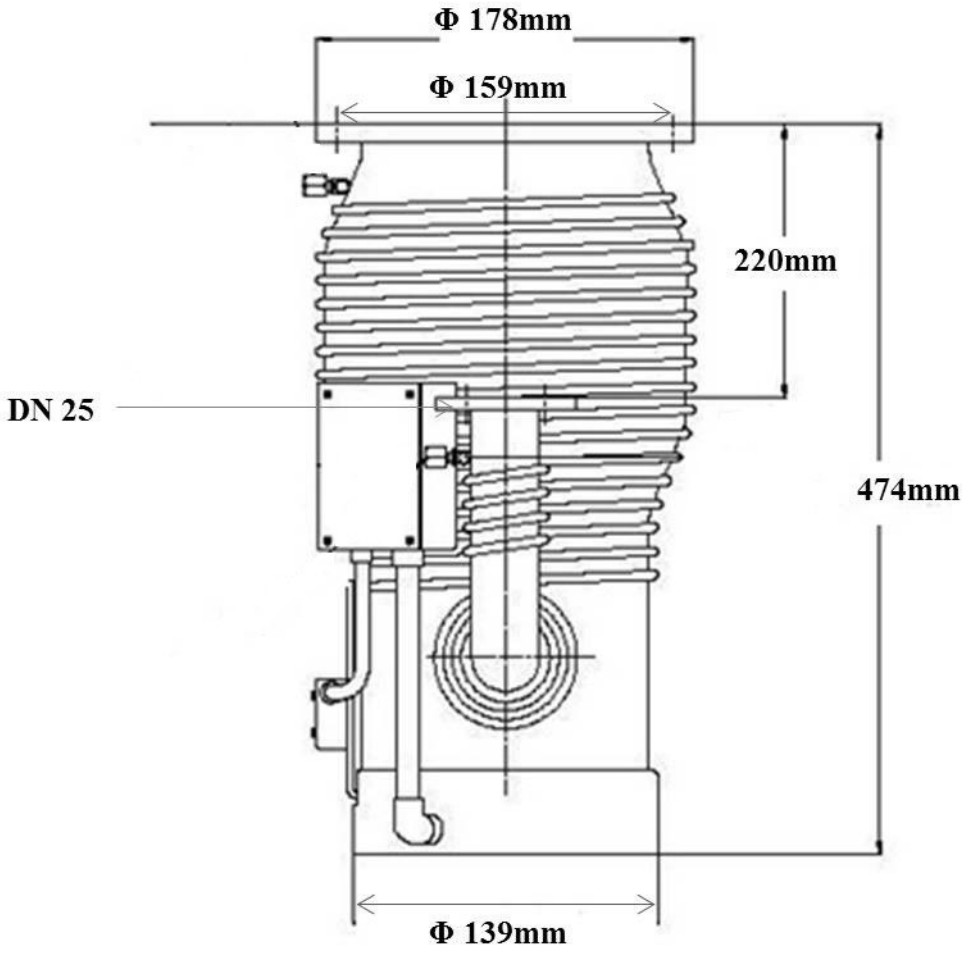


Fig-3: Physical dimensions of DP

3.2.2 Liquid Nitrogen Cold Trap:

This is fitted above the diffusion pump through baffle. It is essentially a double walled container containing LN2 in the central chamber. The inner surface get cooled when LN2 filled and condenses water vapour and other condensable, thereby reduces the pressure by large extent. It requires 1.5 to 5 liters. It serves in two ways; It act as barrier for flow of condensable vapour from pump to system and also act as cryopump for condensable vapors emanating from the system. With the use of LN2 trap ultimate vacuum is 10^{-6} mbar.

In either case, baffles and traps must be installed in order to prevent back streaming of the pump fluid vapor. The pumps also can be vulnerable to mistakes in the operating procedures and no ultimate pressure will be achieved. For instance, the boiling oil or mercury must be protected against oxidation during pump-vent cycles/venting of pump. If this is not done, the pumping fluid will deteriorate and hence the performance of the pump will suffer. The back diffusion can be minimized by placing a trap cooled with liquid nitrogen between the diffusion pump and the vacuum manifold.

There is no limit to the vacuum that could theoretically be achieved with a diffusion pump. However, in practice there is a limit to the base pressure that may be obtained with them. This depends on the design, construction, proper material selection, maintenance of the vacuum line, the placement of efficient traps and baffles, as well as the adherence to proper evacuation, cleaning (heating) and inflating procedures (e.g., purified, dried N_2 or He). With moderate precautions pressures of 10^{-9} Torr can be achieved using diffusion pumps and pressures as low as 10^{-11} Torr.

3.2.3 Diffusion pump (DP) fluid:-

The diffusion pump oil should have the lower vapour pressure, greater resistance to oxidation. Also the fluid should offer thermal and chemical stability. Mainly DP fluids are hydrocarbon, silicon fluid and ether type. Examples of DP oils are given in Table 4.

Table 4: Examples of pumping fluids used in diffusion pumps

Fluid	Composition	Molecular Weight	Attainable Press. at 20°C (in mbar)
Apiezon A	Mixture of hydrocarbons	354	6.5×10^{-05}
Apiezon B	Mixture of hydrocarbons	420	1.3×10^{-06}
Apiezon C	Mixture of hydrocarbons	479	1.3×10^{-07}
Edwards L9	Naphthalene based	407	5×10^{-09}
Silicone DC-702	Mixture of polysiloxanes	530	6.5×10^{-06}
Silicone DC-703	Mixture of polysiloxanes	570	6.5×10^{-06}
Silicone D-704	Single molecule siloxane	484	6.5×10^{-08}
Silicone DC-705	Single molecule siloxane	546	1.3×10^{-09}
Santovac 5	Polyphenylether	446	1.3×10^{-09}
Fomblin 18/8	Perfluoropolyether	2650	2.7×10^{-08}
Mercury	--	201	1.2×10^{-03}

3.3 Roots pumping system:-

Theory and Principle:-

Roots pump is also known as roots blower. It comes under mechanical booster category. It is a frictionless and positive displacement pump. It is a dry vacuum pump (oil free). So, it gives a pure vacuum. It contains two counter rotating lobes, each with a figure eight cross section. The lobes do not touch each other or casing. A clearance between lobes and in between lobes & casing is order of 0.01 inch. In theoretically it can generate a vacuum upto 10^{-04}mbar. But practically it is wrong. To generate such vacuum it needs a backing pump (e.g. rotary pump). Even though the roots blower can discharge directly to atmosphere without any backing pump but it is not advisable in practice. At same time it can start at atmospheric pressure with the backing pump. Its compression ratio is very high (order of 10) and it has higher pumping speed. The pumping speed and operating pressure range of the pump depends on performance, characteristics of the backing pump.

Main advantages of roots pump is their ability to handle large loads in a pressure region where neither rotary nor diffusion pump are fully efficient.

Description and Operation:-

Main components of the roots pumping system are:

(i) A Roots pump/Roots blower

(ii) Vacuum chamber to be evacuated

(iii) Pressure measuring devices(i.e. Pirani gauge)

(iv) Flow meter.

(v) Rotary pump etc.

2D diagram of roots pumping system:-

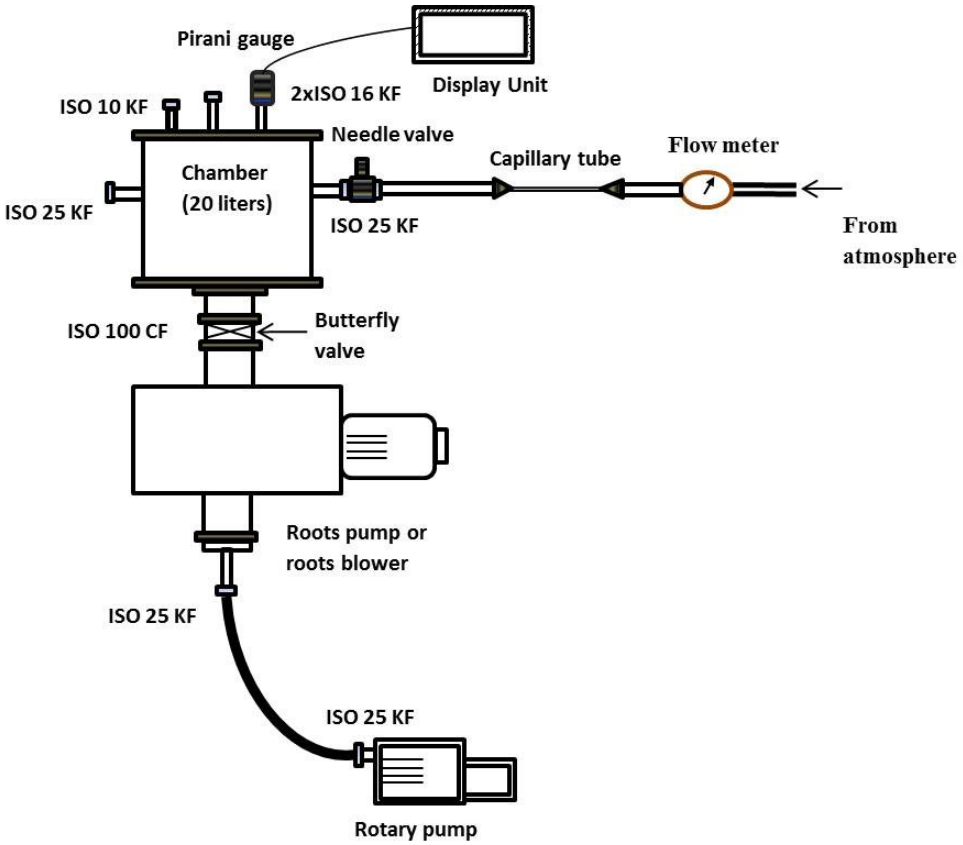


Fig-4: Experimental set-up of roots pumping system

The experimental set-up for roots pumping system is a simple arrangement of rotary pump, roots pump and vacuum chamber with necessary accessories as shown in **Fig-4**.

The pumping speed of roots pump can be calculated using the constant volume method and constant pressure method (refer section 3.1.7).

In constant volume method the needle valve (ISO 25KF, as shown in **Fig-4**) is in closed condition. By starting the rotary and roots pump at a time the pressure reading can be noted down from Pirani gauge controller. The needle valve-capillary tube-flow meter arrangement is only for constant pressure method. Butterfly valve meant for isolation of vacuum chamber from the system. The volume of chamber is of 20 liters. It is mounted with pirani gauge on

the top it. When we want to shut down the system, first OFF the roots pump then after 2-5 min. rotary pump will be shut down. Otherwise there will be back streaming of oil vapors.

The physical specification of roots pump:-

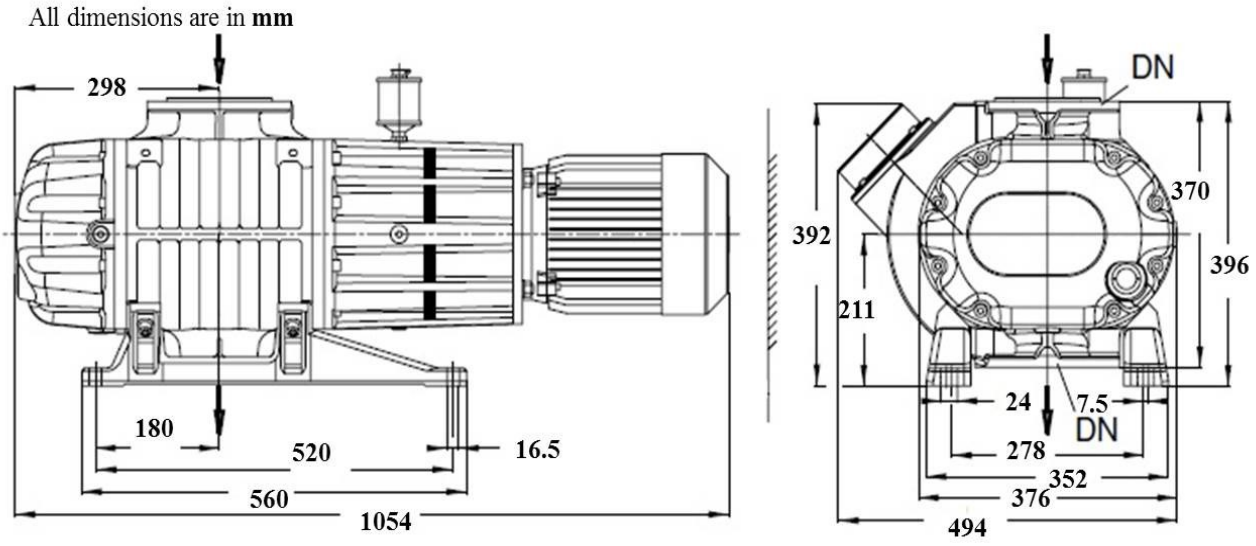


Fig-5: Physical dimensions of roots pump

3.4 Cryo-pumping system:-

Theory and Principles:

A cryopump usually consists of a large number of metal plates cooled to a temperature close to 4.2 K, (either by liquid helium or by a closed cycle cooler).

Refrigerator Cryopumps which are often used for the generation of extremely clean vacuum conditions in industrial processes such as semiconductor production, optical coating, etc.

The design of a cryopump has to combine cryogenic aspects and technological vacuum considerations in a unique manner, as the generation of low temperature it presupposes the existence of vacuum conditions and vice versa. By cryopump we can achieve vacuum upto order of 10^{-11}mbar (10^{-03}mbar to 10^{-11}mbar).

Gaseous substances get bound to the cold surfaces within the pump by means of cryo-condensation, cryo-sorption or cryo-trapping. A cryopump is defined as a vacuum pump which captures the gas by surfaces cooled to temperatures below 120 K. To achieve vacuum in a closed volume means, simply speaking, to remove all molecules in the gaseous phase within this volume. All gases, except helium, hydrogen and neon, will condense on surfaces cooled to below about 60 K. Therefore, once liquid helium at 4.2 K is introduced into a vacuum vessel, all the residual gases that are normally present will condense (or cryopump).So, In order to be able to produce high or ultra-high vacuum the cold surface (cryo panels) must be cooled to a sufficient low temperature.

Depending on the type of cooling system used a difference is made between *refrigerator cryopump*, bath cryo pump and evaporator cryopump.

A compressor unit, flex lines and backing pump are required to operate a refrigerator Cryopump with helium gas under high pressure to generate the low temperatures.

The backing pump is employed to evacuate the vacuum chamber to the cut-in pressure. Further it is employed to generate the cryopump.

At the pump inlet is the 65-80 K array, which is thermally connected to the first stage of the refrigerator by the radiation shield.

Indium foil is used at the mechanical junctions to improve thermal conductivity. Water vapor is the primary gas that is condensed on the inlet array. Without the optically opaque inlet array, water vapor would condense on the 15 K array severely limiting its ability to pump oxygen, nitrogen and the non-condensable gases, helium, hydrogen and neon.

The diagonally positioned plates of the 10-15 K arrays serve two functions: the top surfaces are used to pump oxygen, nitrogen and argon, while the sorbent or activated charcoal is attached to the underside of each array is used to cryo-adsorb the three non-condensable gases (i.e. hydrogen, neon and helium).

The cross-sectional view of cryopump head is shown in **Fig-6.**

Formula for the pumping speed (litrs. /s) of a cryopump is given by

$$S = c * A_{inlet} * \sqrt{\frac{R_0 T}{2\Pi * M}}$$

Where

A_{inlet}= inlet cross section (m^2)

R_0= gas constant

c= capture coefficient

M=Molecular mass of gases

The ultimate pressure P_{ult} of a cryo-condensation pump results from the saturation vapour pressure P_s of the condensed gas at the cryopanel temperature Tc taking into account the system and gas temperature T (Normally room temp.).

The ultimate pressure can be given as

$$P_{ult} = P_s * T_c \left(\frac{T}{T_c} \right)$$

Similarly the effective pumping speed of a cryopump as a function of the working pressure P is given by the equation as follows:

$$S_{eff} = S_{nom} \left(1 - \frac{P_{ult}}{P} \right)$$

Where S_{nom}= nominal pumping speed at $P=10^{-4}$mbar.

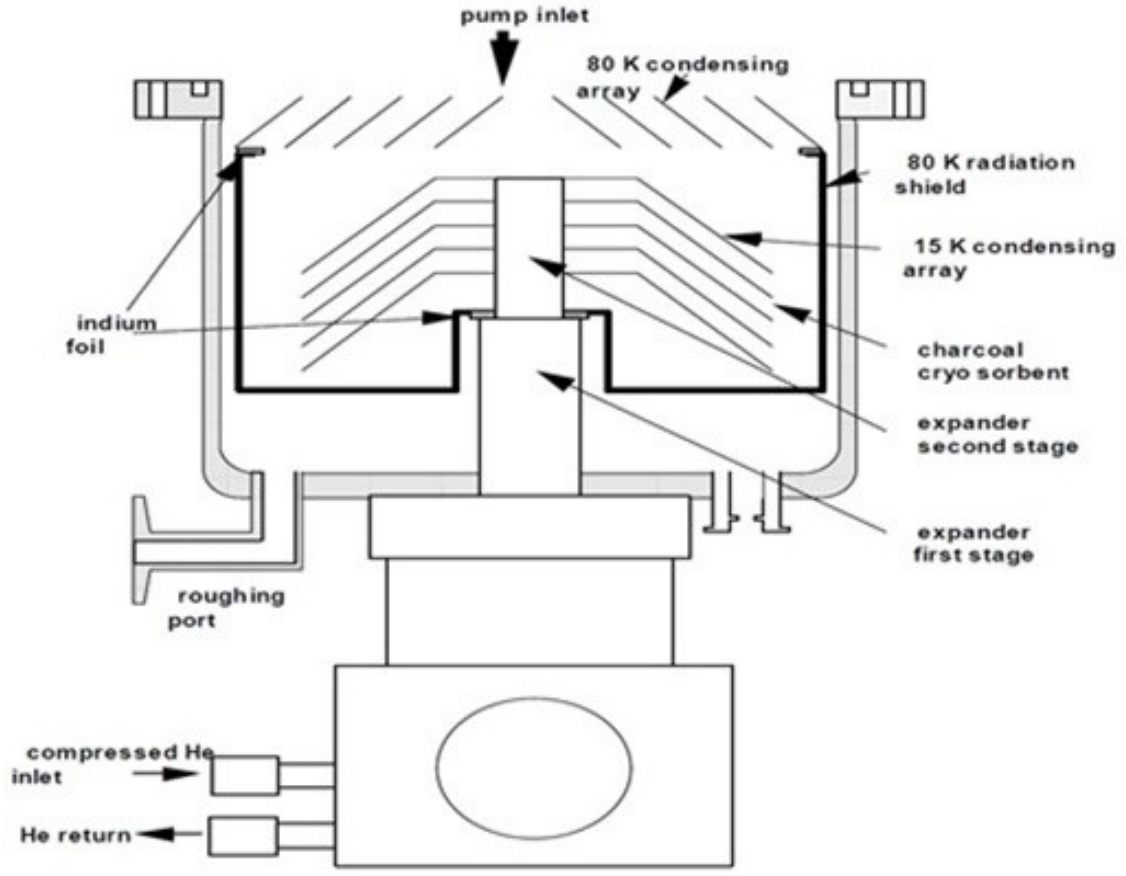


Fig-6: cross-sectional view of compressed helium cryopump body

Experimental set-up of Cryopumping system:-

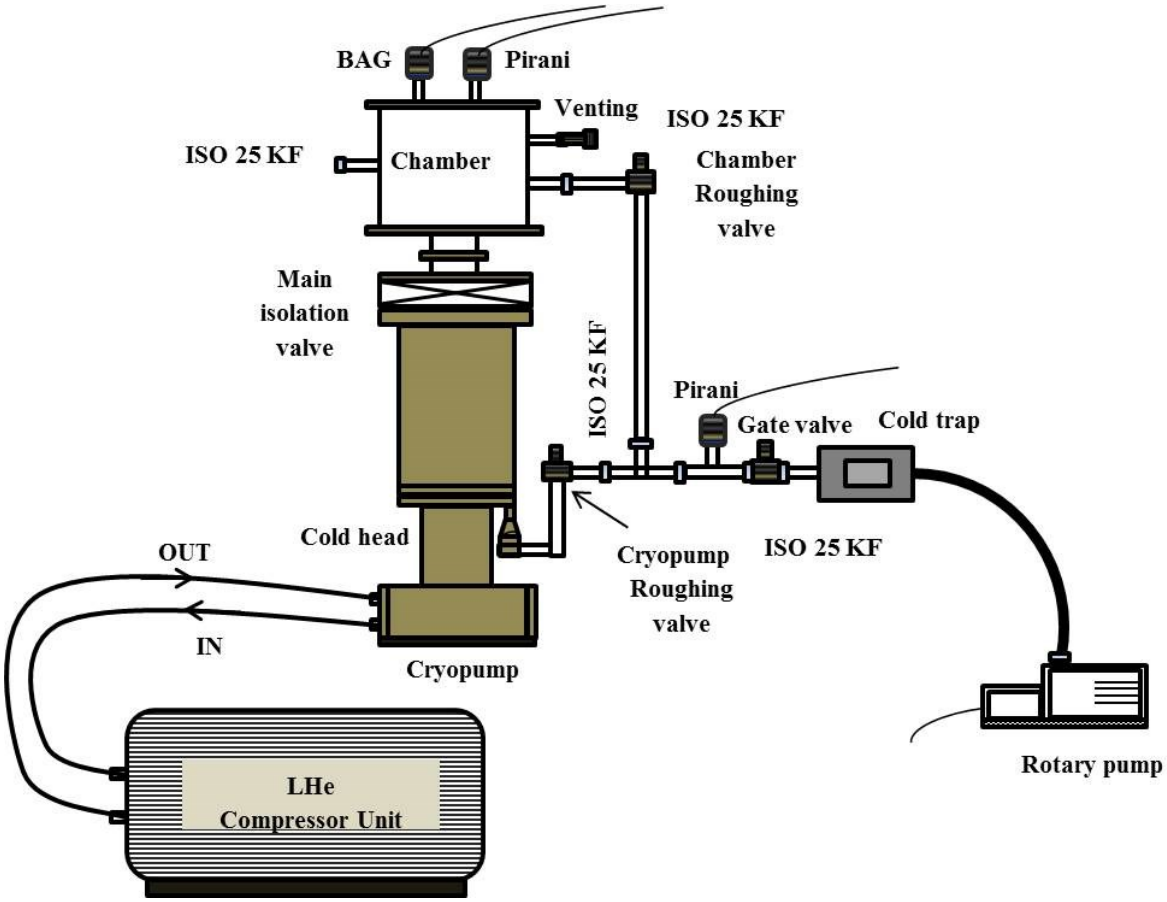


Fig-7: Experimental set-up of cryopumping system

Description and Operation of cryopumping system:-

Main components of cryopumping system are as follows:-

(i) Cryopump.

(ii) Refrigeration or LHe based compressor unit.

(iii) Power supply and display unit.

(iv) Pressure measuring devices(i.e. gauges)

(v) Rotary pump

(vi) Cold trap

(vii) Vacuum chamber etc.

The arrangement for testing the performance of a cryopump is shown in **Fig-7.**

The pump and chamber pre-evacuate with a rotary pump to a vacuum level of 10^{-2}mbar.

The pre-evacuation process performs by using roughing valves of both cryopump and chamber. LHe consists of high pressure (OUT, refer Fig-5) and low pressure (IN) flexible pipes. The aim of compressor is to maintain the temperature of first stage (65-80 arrays, refer Fig-4) and second stage (10-15 array) arrays. As the size of the backing pump depends on the size of vacuum chamber. The vacuum chamber volume is 20 liters and for that $15m^3/h$ is sufficient to evacuate that chamber. The specification of components is given in the **Table-8, Chapter-4.** The refrigerator-cooled cryopump are cooled by a two stage refrigerator operating on the Gifford –McMahon principle. The refrigerator involves cold head and compressor unit connected via two flexible pressure tubes. The refrigerator uses a closed helium gas cycle where the gas compressed by the compressor is expanded in two successive stages at the cold head and thereby cooled. The Pirani gauge and BAG are mounted on the top of vacuum chamber to measure pressure during the process. Isolation valve is meant for isolation of vacuum chamber from the system. Cold trap or cryo trap is used to achieve a hydrocarbon free operation. The function of cryo trap is it prevents oil vapors from the roughing pump from entering to the cryopump and the vacuum chamber.

The physical specification of cryopump:-

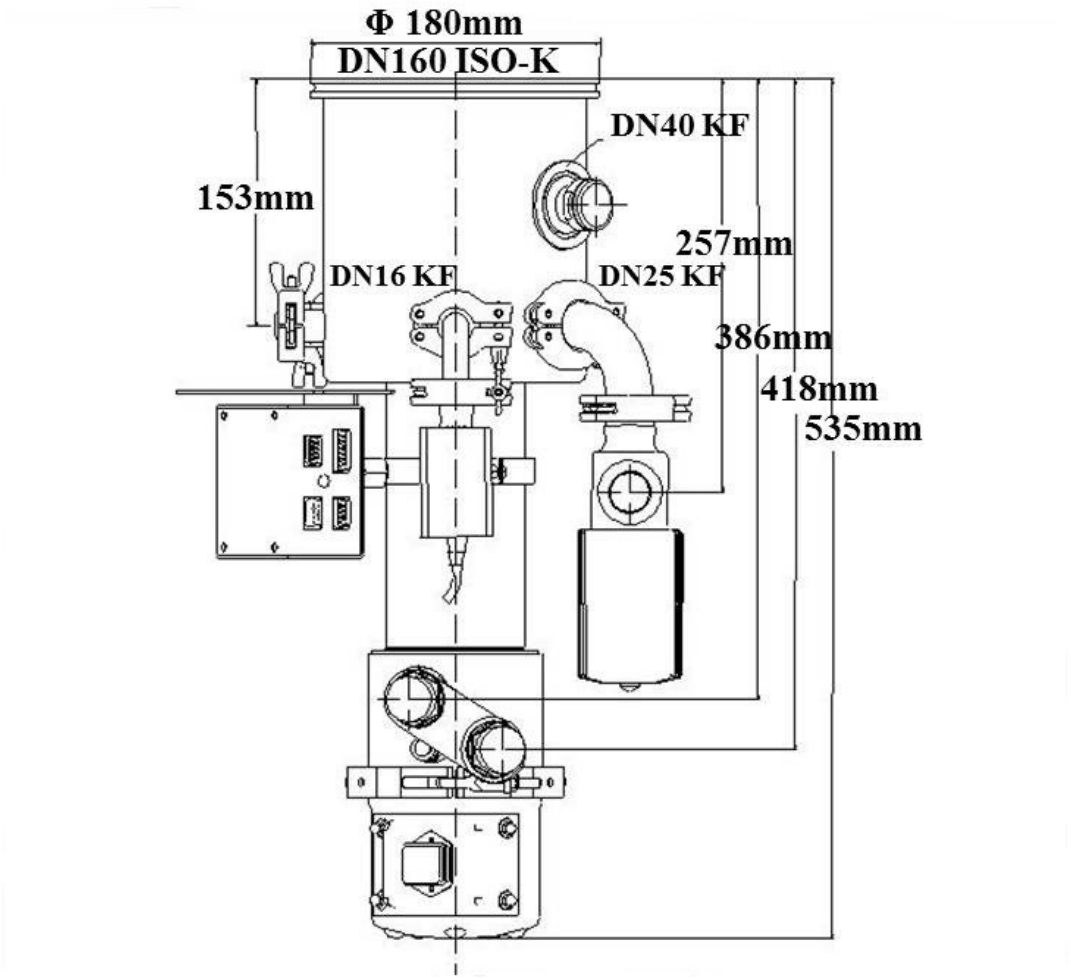


Fig-8, Physical specification of Cryopump

3.5 Ejector pumping system:-

Theory and principle:-

It is simple structure comprised a suction chamber, diffuser and nozzle. A vacuum ejector is an ejector system in which air is the motive fluid. It is also known as air ejector. Its construction is similar to a water ejector or steam ejector. It works on the principle of ventury effect operate by passing motive air or gas through an expanding nozzle. The nozzle provides controlled expansion of the motive gas to convert pressure in to velocity which creates a vacuum with in the body chamber to draw in and entrain gases or vapour. The motive gas and suction gas are then completely mixed and then passed through the diffuser or tail, where the gases velocity is converted in to sufficient pressure to meet the predetermined discharge pressure. A vacuum ejector has two inlets;

One (Inlet1) is to admit motive fluid, usually other than steam, such as air, nitrogen, ethylene glycol etc. The other (Inlet2) is to admit the gas to be evacuated or pumped out.

Motive fluid, at high pressure and low velocity enters the Inlet1 and exits the fluid nozzle at designed suction pressure. The motive fluid having supersonic velocity entrains the gas to be evacuated from vacuum chamber through Inlet2. The nozzle throat diameter controls the amount of motive fluid to pass through the nozzle at a given pressure and temperature.

Ultimate pressure under no load is 12 Torr with single stage of liquid ring vacuum pump, 6 Torr with double stage of liquid ring vacuum pump.

Two Stage Ejectors

Staging of Ejectors is required for more economical operation when the required absolute vacuum level is reduced.

Two stage Vacuum Ejectors generally cover vacuum ranges between 5-8mm mbar to 130mbar

Ejector selection procedure

The following is a suggested procedure for rating and selecting an ejector system for vacuum operation:

(i) Select the number of stages

(ii) Estimate the compressed air consumption

(iii) Number of nozzles and its diameter.

The specification of ejector pump:-

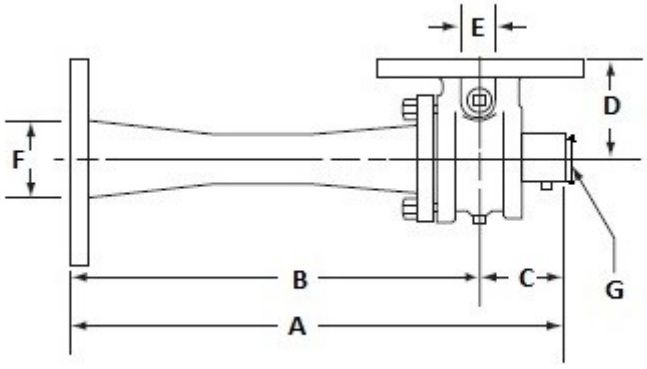


Fig-9: Physical dimensions of ejector pump

Unit dimensions				**connections**			**Net weight(kg)**
A(mm)	B(mm)	C(mm)	D(mm)	E(inch)	F(in.)	G(NPT)	22(approx.)
597	470	127	102	2	2	1 ½	

3.5.1 Two stage ejector pump using liquid ring pump:-

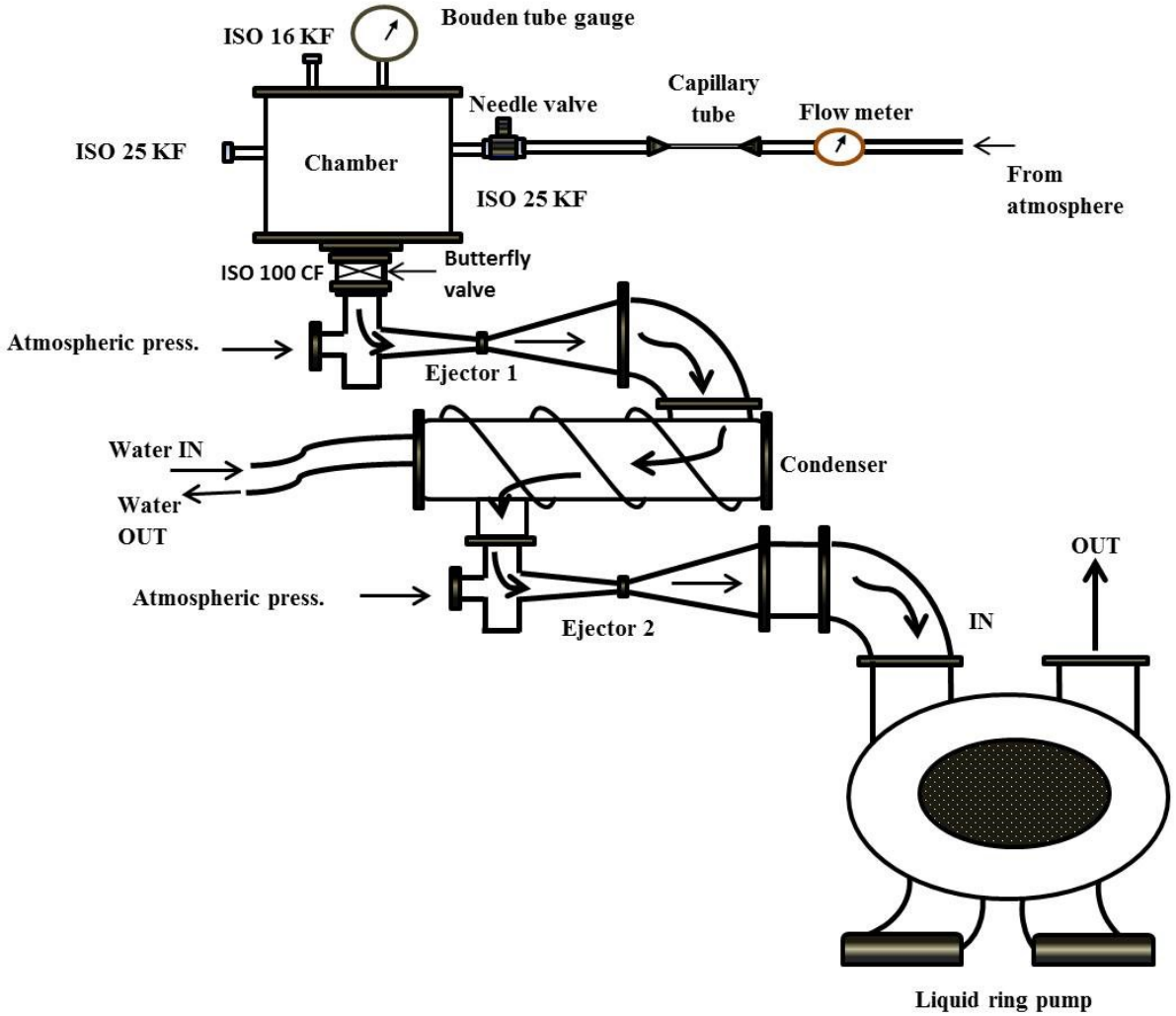


Fig-10, Experimental set-up for ejector pumping system with liquid ring pump

Description and operation:-

The experimental set-up of two stage ejector pump with liquid ring is given in the **Fig-10.**

Two stages means two ejector pumps connected back to back through a condenser. The function of condenser is to maintain the temperature of operating fluid flowing through it. The maximum operating temperature of liquid ring is 150°C. If exceeded this temperature liquid ring pump get over heated. So, condenser is provided with cooling water connection.

Another function of condenser is traps the oil vapors during back streaming. The vacuum chamber (20 liters) to be evacuated is mounted on the suction port of the ejector pump. A flow meter-capillary tube-needle valve arrangement is connected with vacuum chamber to calculate the pumping speed of ejector pumps. The methods used for calculation of pumping speed are constant volume method and constant pressure methods (ref section **3.1.7).**Butterfly valve connects vacuum chamber and ejector pump system. This valve is for isolating the chamber from the system. This system gives a rough vacuum but it is pure. The vacuum can be generated upto 4-6 mbar by the system.

3.5.2 Two stage ejector pump using compressor:-

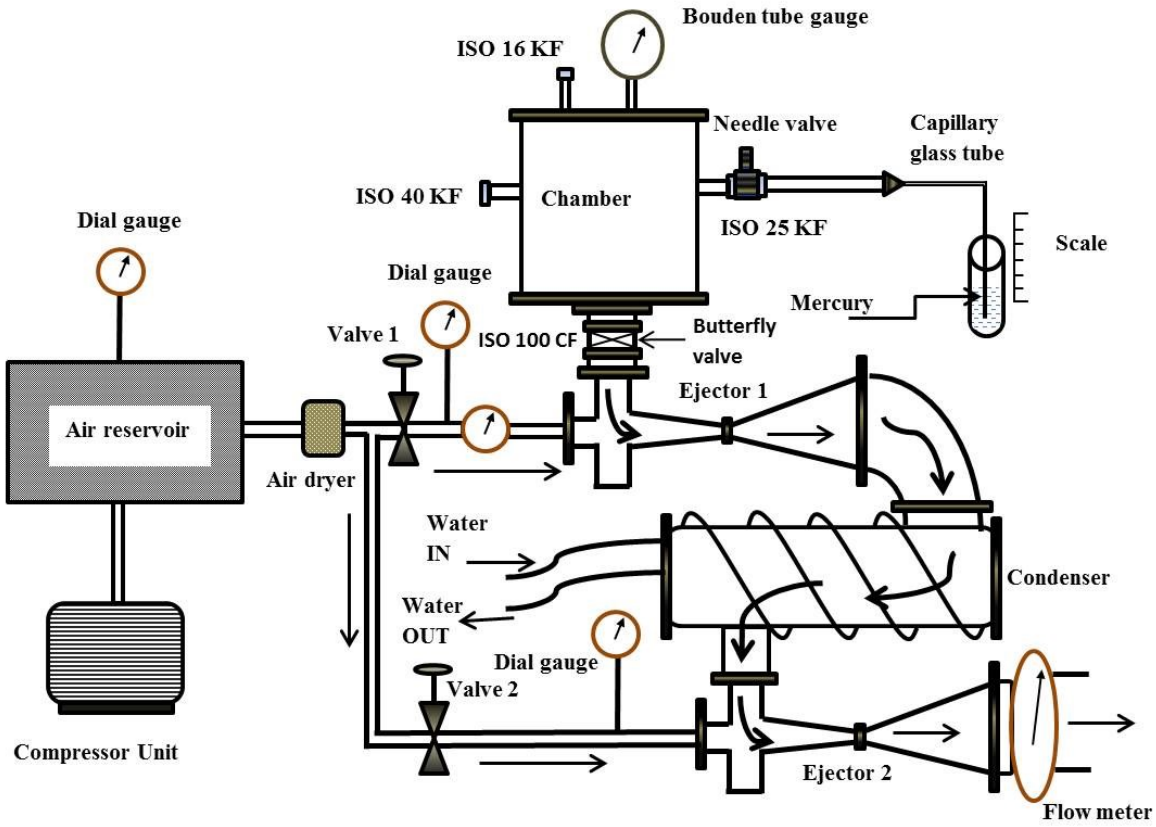


Fig-11, Experimental set-up for ejector pumping system with compressor

Description:-

The experimental set-up of ejector pumping system with air compressor is given in the **Fig-11.**

The operation and principles are same the previous one i.e. the ejector pumps using a liquid ring pump. The difference is only the connections. Here the compressor unit is connected to the system at the inlet of the 1st stage ejector pump. Whereas the liquid ring pump is connected at the discharge end of 2nd stage ejector pump in the previous experimental set-up. Another difference is the pumping speed calculation techniques. Here the pumping speed calculation is performed by constant pressure method using an arrangement of needle valve-glass capillary tube-mercury jar (refer section **3.1.7.3)**. The compressed air enters at the inlet1 of the 1st stage ejector with high pressure and entrains the gas from vacuum chamber through the inlet2. The discharge of the 1st stage ejector (ejector1) enters to the 2nd stage ejector (ejector) through inlet2 of 2nd stage ejector. A flow meter is connected to the discharge of ejector2 as shown in the above figure. Air control valves are connected with the system to control the air flow. The compressed air enters to ejector1 is not same with the air enters to ejector2. Air enters to ejector1 is approximately equal to 2/3 of the air pressure at the inlet of ejector2.

In this way the experiments will be performed.

3.6 Calibration of vacuum gauges using primary gauges:-

Vacuum measurements are important tool for vacuum systems. They must measure pressure many orders of magnitude smaller than atmospheric pressure. The accuracy of vacuum gauges ranges from application of vacuum fields to fields.

Because of the increasing deviations from conditions of molecular flow at pressure above 10^{-02}Pa, calibration in this range are performed against molecular drag gauges which have been calibrated against primary standard. Molecular drag gauges are used because of their linearity, reproducibility and precision in this pressure ranges. Almost all mechanical vacuum gauges (primary gauges) are independent of type of gas whereas all secondary gauges depend on the type of gases.

After design and manufacturing, it is necessary to calibrate a pressure gauge. To calibrate a newly manufactured gauge or recalibration of a gauge require a reference gauge. The reference gauges are also called primary gauges. Gauges calibrated with reference to primary gauge are called secondary gauges.

For instance,

(i) Primary gauge: McLeod gauge, capacitance gauge etc.

(ii) Secondary gauge: Pirani gauge, penning gauge, ionization gauge etc.

Normally, High vacuum is measured using a combination of Pirani and Penning type gauges. The Pirani gauge operates in the range 10 mbar to 10^{-03} mbar and the Penning in the range 10^{-02} mbar to 10^{-07} mbar. Thermocouple gauge ranges from 10^{-01}mbar to 10^{-03}mbar. The

calibration of these gauges (and some others like ionization gauges, thermal conductivity gauges etc.) depends on the type of gas in the system.

Vacuum in the range from 10 to 1000 mbar is normally measured with reasonable accuracy using a simple capsule or dial gauge. Other types of gauge are available, for example, piezoelectric gauges, mass spectrometer and Baratron gauges, which allow accurate remote measurement.

So, aim of the experiment was to calibrate pirani and penning gauge by using a primary gauge.

Schematic diagram of a calibration system:-

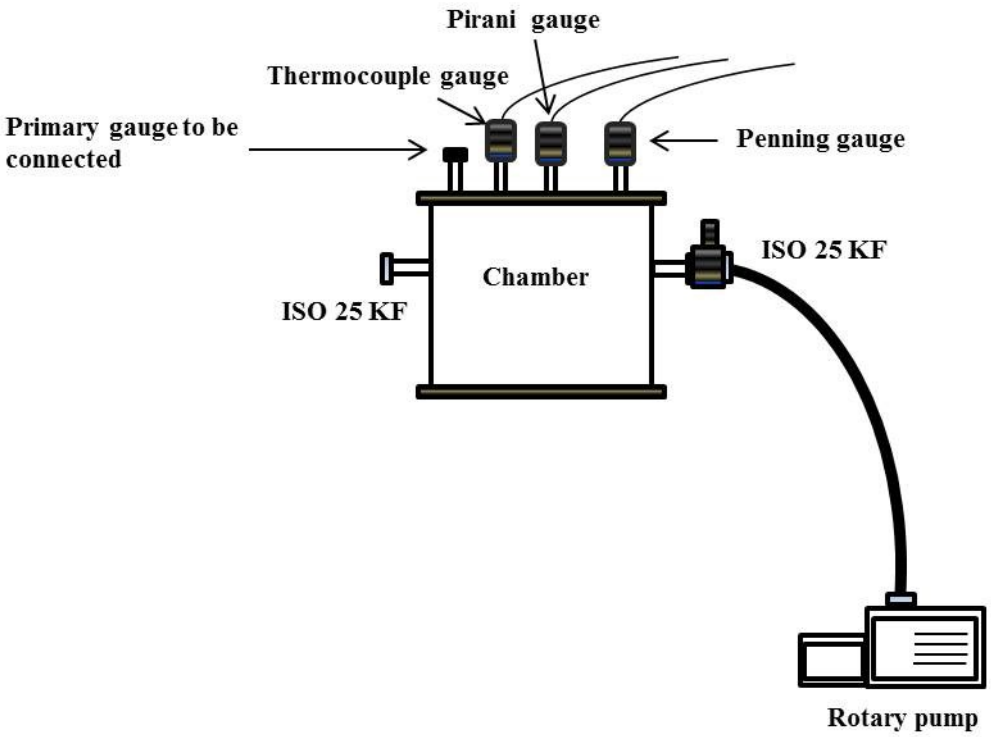


Fig-12, Experimental set-up of calibration of vacuum gauges

Description:-

The experimental set-up involves a vacuum chamber (20 liters), pressure measuring devices both primary & secondary gauges and a rotary pump. Pirani, thermocouple gauge and penning gauges are secondary gauges whereas McLeod gauge (or capacitance gauge) is

primary gauge. The Primary & secondary gauges are mounted on the top of vacuum chamber. The chamber to be evacuated is connected with rotary pump through a needle valve as shown in the **Fig-12.** The needle valve is meant for isolation of the chamber from the backing pump. The secondary gauges are calibrated in comparison with the pressure range of primary gauge. That means the lower pressure range and higher pressure of a particular secondary pressure gauge is calibrated according to the lower pressure range and higher pressure range of primary gauge.

3.7 Vacuum Insulation:-

3.7.1 Theory:-

Needless to say, high performance thermal insulation is increasingly required to reduce energy consumption or to save valuable space. A superior thermal insulation can be achieved by vacuum insulation, it has no doubt. As the heat transfer phenomena occurs in three ways, i.e.

(i) Heat transfer due to conduction

(ii) Heat transfer due to convection and

(iii) Heat transfer due to radiation.

So, our aim is to prevent the heat transfer by vacuum insulations.

Vacuum insulation can be done in three ways:-

a) Plain vacuum insulation

b) Powder vacuum insulation and

c) Multilayer vacuum insulation.

The gas molecules are responsible for the heat conduction in the vacuum insulation. So, for plain vacuum the free mean path of molecules must be greater than the distance between the two surfaces. Similarly, for powder (porous) vacuum insulation the distance between two molecules should be greater than the diameter of the individual molecule. Sometimes multilayer insulations are preferred to reduce the radiation heat transfer.

In plain vacuum insulation, the gas molecules from the vacuum insulation panel (vacuum chamber) are pumped out by vacuum pumping systems to create vacuum.

In powder vacuum insulation, the low vacuum evacuated insulation panel is filled with powder materials to reduce the heat transfer process.

The thermal conductivity of the fully evacuated core material, gas pressure is the most important indicator of quality of a vacuum insulation.

For any core material there is a relation between the thermal conductivity λ and gas pressure p_{gas}, with the typical pressure $p_{1/2}$ as parameter, which depends on the pore size of the core material. In most cases it can be described by the formula:

$$\lambda = \lambda_0 + \lambda_g \left(1 + \frac{p_{1/2}}{p_{gas}} \right)$$

Where

λ_0 being the thermal conductivity at zero gas pressure and λ_{gas} the thermal conductivity of the gas at atmospheric pressure

The total thermal conductivity may be described by formula:

$$\lambda_{tot} = \lambda_g + \lambda_r + \lambda_s$$

λ_r =radiation transfer

λ_s=solid conduction within the materials

Heat flux is given by

$q = h*\Delta T$

h=heat transfer coefficient (W/m^2K)

ΔT =temp. difference =$T-T_\infty$ or T_1-T_2 (K) [$T_1>T_2$]

And $q=\lambda*\Delta T/L$ L=distance between two surfaces (mm)

So, we can establish a relation between heat flux and gas pressure for above first and second cases.

And we can establish a relation between heat flux and number of layer for third case.

i.e. **Heat flow= f (no. of layers)**

As for both plain vacuum insulation and powder vacuum insulation the heat flow is function of molecules present the medium or pressure.

i.e. **Heat flow= f (p)**

Three experimental set-ups are proposed on the basis of vacuum insulation concept. First experimental set-up is for plain vacuum insulation, second is for powder vacuum insulation and the third set-up is for multilayer vacuum insulation.

3.7.2 Boil-off rate:-

The thermal conductivity test methods may be divided into three general categories which are defined in terms of the methods used to measure the amount of heat transferred through the specimen. These are

(i) Boil-off calorimetry

(ii) Electrical-input methods and

(iii) Indirect method

Boil-off calorimetry and electrical input are the most widely used methods, and they have been applied to all types of cryogenic insulations. The category of indirect method includes transient and heat-flow-meter procedures.

Here only the first method is used to calculate the boil-off rate of the vacuum insulation systems.

3.7.3 Boil-off calorimetry:-

A**s** the name implies, the amount of thermal energy passing through the test specimen is determined from a measurement of the volume of gas vaporized from a fluid of known latent heat of vaporization at a constant temperature and pressure.

The formula used for boil off rate can be given as follows:

Boil off rate of LN_2= Total heat transfer/Latent heat of evaporation of LN_2

$$\textbf{Boil-off rate} = \frac{Q}{Q_{LN_2}} \qquad \text{(in } m^3\text{/s or litrs/s)}$$

Where, $Q = \frac{\varepsilon\sigma A(T_0^4 - T_i^4)}{n+1}$, Total heat transfer (in J/s) (details given in the **section 3.7.6)**

n= no. of layers of MLI blanket, n=0 for both plain vacuum and powder vacuum insulation.

Q_{LN_2} = Latent heat of evaporation= (Latent heat of LN_2 x density of LN_2) (units in J/liters)

Latent heat of LN_2 =199 J/g or KJ/kg, density of LN_2=1.25 g/liters

A= area of the vacuum insulation panel or vacuum chamber

ε= emissivity of MLI blanket= 0.035 for polyester-aluminum blanket=0.1

T_0=Outer surface temperature of chamber, mostly room temp. (300K)

T_i=Specimen temperature (77K)

The experimental set-ups involve following main components:

(i) Main chamber (outer chamber)

(ii) Inner powder chamber (for powder vacuum insulation set-up only)

(iii) Flow meter

(iv) Water bath(Glass jar fitted with cork)

(v) Specimen

(vi) Lower guard

(vii) Upper guard

(viii) Valves

(ix) Liquid nitrogen

(x) Connecting pipes etc.

The main chamber (outer chamber) designed is same for above three vacuum insulation set-ups. The 3D diagram of main chamber is given in **Fig-13.**

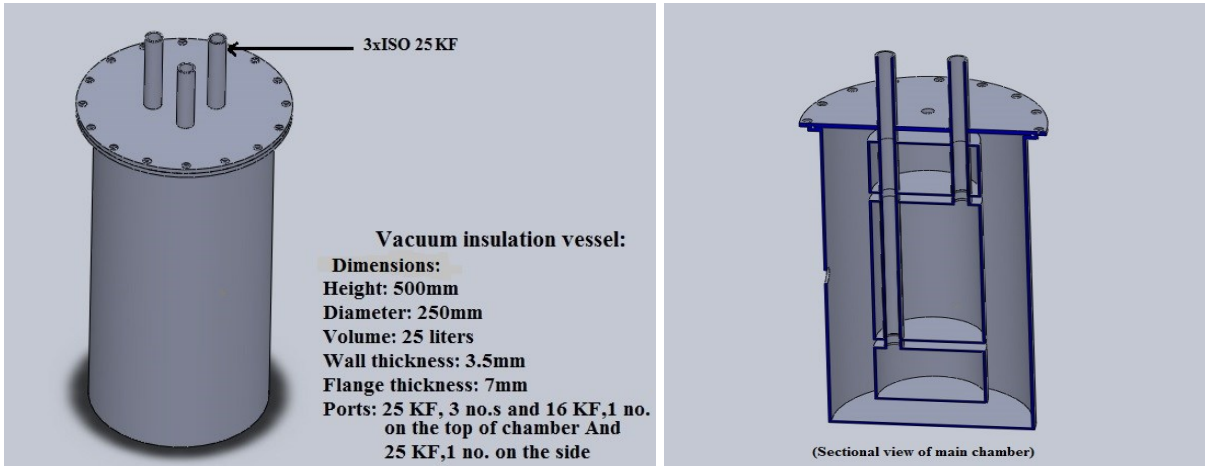


Fig-13, Main vacuum chamber for vacuum insulation experimental set-ups.

3.7.4 Plain Vacuum Insulation: -

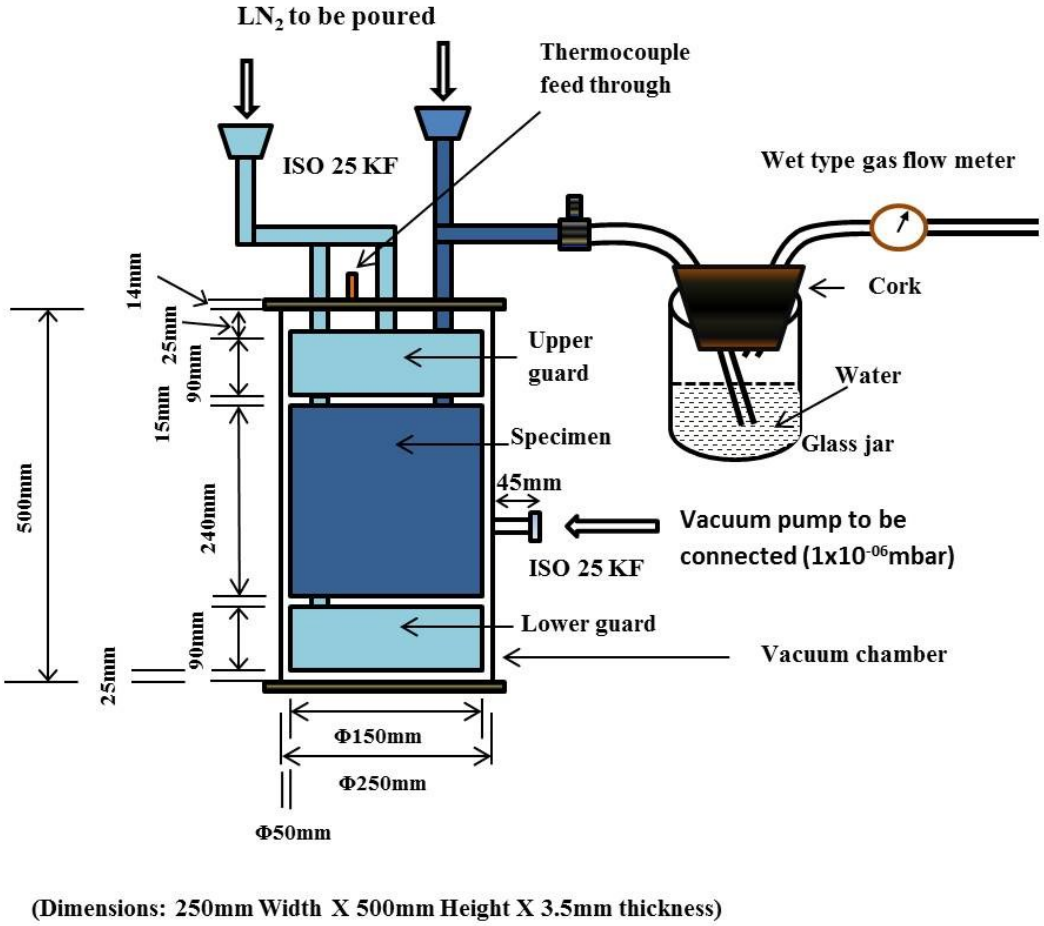


Fig-14: Experimental set-up for plain vacuum insulation system

Description of plain vacuum insulation set-up:-

The plain vacuum insulation system consists of a vacuum chamber which is to be evacuated by a vacuum pumping system to produce the vacuum of 10^{-6}mbar. The vacuum chamber contains a lower guard, specimen and an upper guard as shown in the **Fig-14.**

Chamber is mounted with a thermocouple feed through and openings of the specimen, upper guard and lower guard through which LN_2 to be poured.

The boil-off rate of specimen is to be calculated. So, a wet type flow meter is connected to specimen through needle valve and a water saturator bath as shown in the above figure.

3.7.5 Powder Vacuum Insulation: -

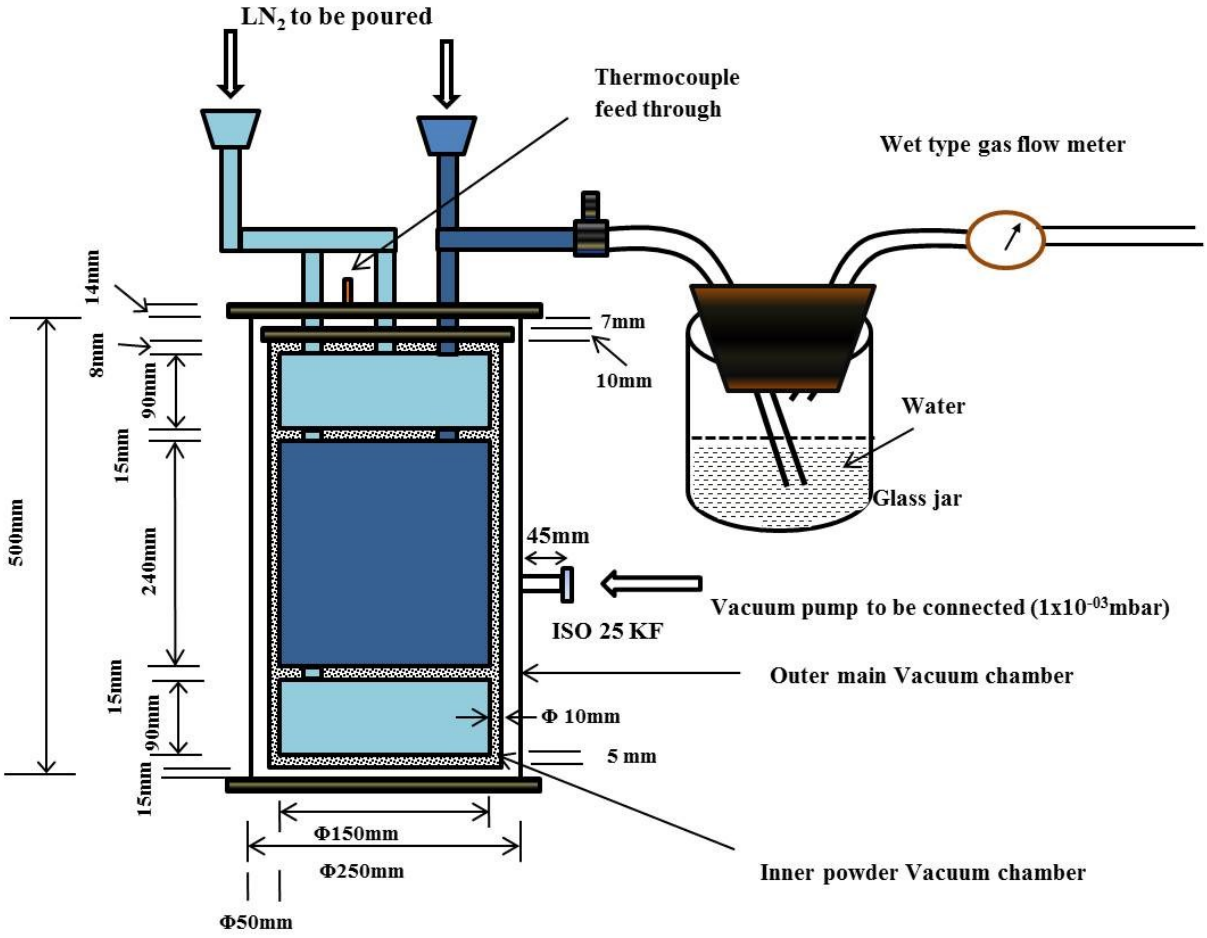


Fig-15, Experimental set-up for powder vacuum insulation system

Description:-

The experimental set-up of powder vacuum insulation system is same as plain vacuum insulation system except the inner powder vacuum chamber. The powder chamber is meant for filling the porous powder materials (e.g. perlite powder) in it so that the thermal conductivity through the system reduces. The experimental set-up is given in the **Fig-15.**

The outer main chamber will be connected to the vacuum pump to maintain the vacuum level of 10^{-3}mbar. The flow meter is connected to the specimen to calculate the boil-off rate

of the specimen. This type of insulation typically has a thermal conductivity 10 or 10^2 order of magnitude greater than MLI.

The equation of heat transfer to the specimen from outside will be given as

$$Q= h*A*(T_s-T_{ref.})$$

Where, h=heat transfer co-efficient

A=Area of specimen

T_s= Outer surface temperature of specimen, T_{ref}=Outer surface temp. of main chamber

This equation is required in calculation of boil-off rate of specimen.

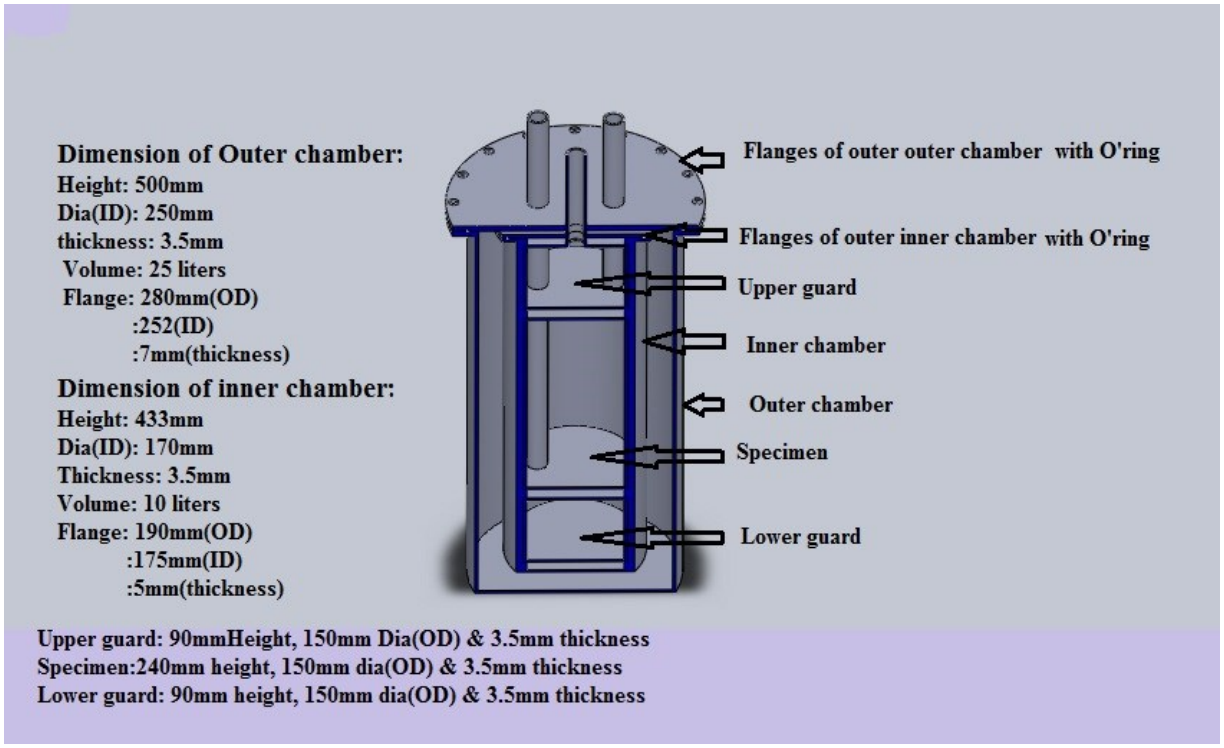


Fig-16, Sectional view of chambers of powder vacuum insulation system

3.7.6 Multilayer vacuum insulation(MLI):-

Description:-

The multilayer insulation system consists of a chamber, flow meter arrangement to calculate boil-off rate and a specimen guarded with two guards on the top & bottom. The construction is same as plain vacuum insulation system. The lower guard-specimen-upper guard is bounded with MLI blanket (polyester-aluminum blanket) to prevent radial radiation heat transfer.

Vacuum should be maintained ultrahigh vacuum. On the side of the chamber a port is present to connect the ultrahigh vacuum pumping system as shown in the **Fig-17**

Heat inflow,

$$Q_{MLI}= \frac{\in \sigma A(T^4_{out} - T^4_{in})}{n+1} \quad J/s$$

Where, n= no. of insulating layers

σ =5.57x10^{-08} w/m^{2}K^4

$\in$ =0.035, for polyester-aluminum combination= 0.01

(approx. for two sided MLI)

A=Area of cylindrical chamber= $\pi * D * L$ (m^2)

D=Diameter of chamber

L=height of the vacuum chamber

T_{in}=Outer wall temperature of specimen.

T_{out}=Outer wall temperature of outer chamber

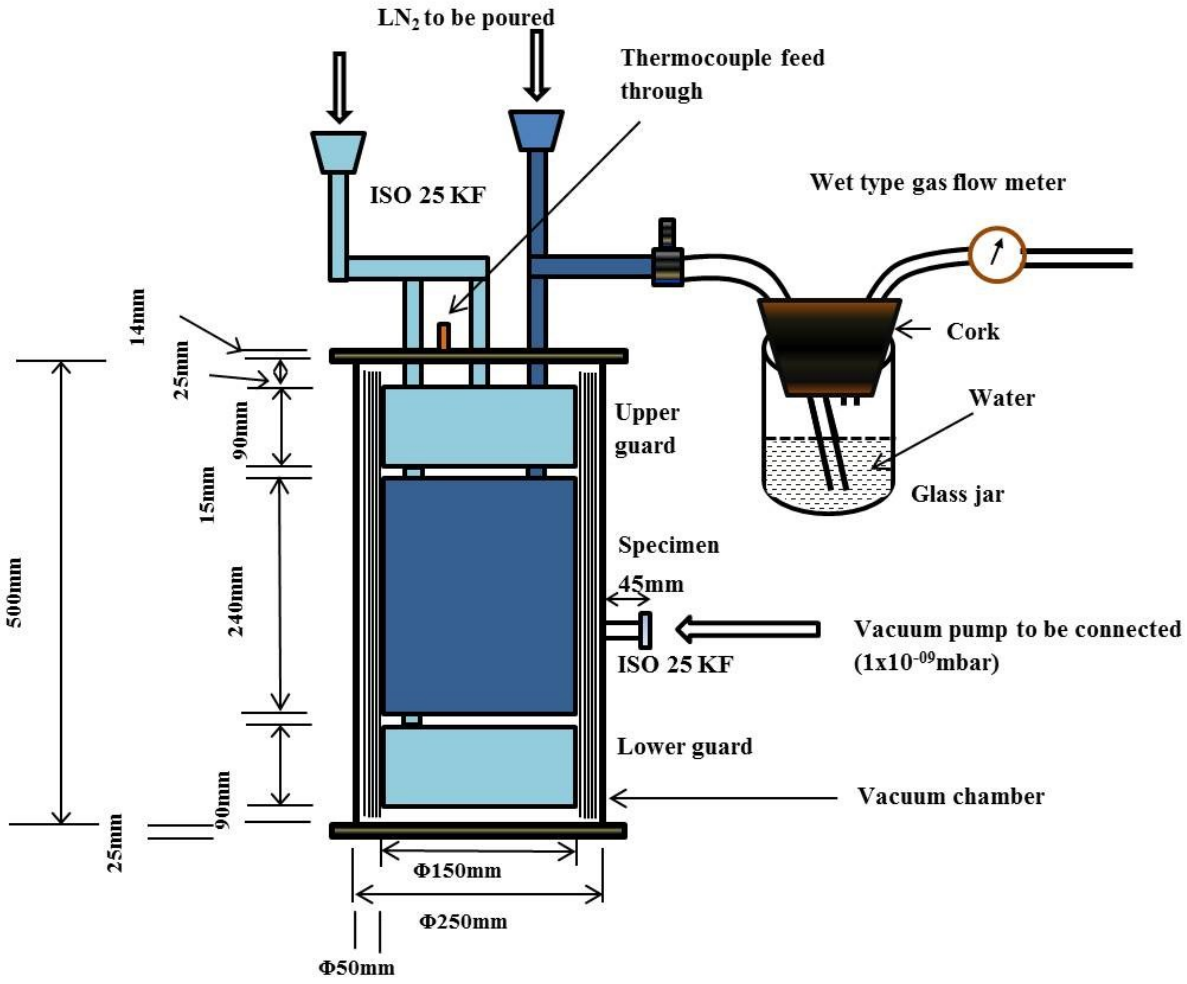


Fig-17, Experimental set-up for multilayer vacuum insulation system

The thermocouple is a temperature sensor which measures the temperature inside the chamber. Thermocouple sensor is coupled with the display unit through thermal feed through.

CHAPTER-04:

LIST OF COMPNENTS REQUIRED AND BILL OF MATERIALS PROPOSED.

4.1 Diffusion pumping system:

List of components required

(i) Diffusion pump

(ii) Rotary pump

(iii) Vacuum chamber

(iv) Pressure measuring devices(Pirani and Penning gauges)

(v) Connecting pipes.

(vi) Valves

(vii) Flow meter

(viii) Capillary tube

(ix) Diffusion pump oil & Rotary pump oil

(x) Water chiller and

(xi) Coupling and fittings etc.

Table-5: Bills of material proposed for diffusion pumping system:-

Sl. No	Name of components	Details of components	Qty
1	Vacuum pumping system	Model No. VS-114D (Specification is given in the **Table-6)**	1
2	Cylindrical vacuum chamber	**20 Liter** capacity, (L/D=1, Ports- 1xDN 100 ISO 65 NB Flange on bottom, 3x DN 16 ISO-KF and 1x DN 10 KF on top, 3x DN 25 KF & 1xDN 60 KF on either sides.) **Dimension 300L x 300D**	1
3	Flow meter	Flow rate range: 0-20 sccm	1
4	Capillary tube	OD=5mm, thickness=0.4mm, Length=60mm, with flange type (KF10) end fits.	10
5	Needle valve	DN25 KF, SS	2
6	Pirani gauge with controller	1 mbar – 1 x 10^{-3} mbar, KF type coupling.	2
7	Penning gauges with controller	5 x 10^{-2}mbar- 1 x 10^{-6}mbar, KF type coupling	1
8	Centering O-ring	DN40 KF, Viton	1
9	Centering O-ring	DN25 KF, Viton	6
10	Centering O-ring	DN16 KF, Viton	3
11	Hinged Aluminum Clamps	DN 40 KF	1
12	Hinged Aluminum Clamps	DN 25 KF	6
13	Hinged Aluminum Clamps	DN 16 KF	3
14	Blank flange	DN 40 KF, SS	1
15	Blank flange	DN 25 KF, SS	2
16	Blank flange	DN 16 KF, SS	1
17	Teflon adjustable Reducer with fittings	DN 25-DN 05	2
18	Silicon vacuum grease	100g	1
19	DP oil	DC704, 100ml	1

Table-6: Details of Model No.: VS-114D (According to Hind High Vacuum Company Pvt. Ltd, Bangalore)

Sl. No	Component Name	Specification of components	Qty
1	Diffusion pump	Model: OD114D, 280 l/s, Ult. Press. $2x10^{-7}$mbar, 3 stage jet, SS304 body,	1
2	Double stage Rotary pump	Model: FD-12, 200 l/s, Ult. Vacuum $1x10^{-3}$ mbar.	1
3	Liquid Nitrogen Trap	Model: LNT-114, 4" size (4 – 5 litrs of LN_2 to be poured to operate the system for 5 working hours)	1
4	Vacuum Collar	A 0.9 liter vacuum collar is mounted above the high vacuum valve with flange type connection	1
5	High vacuum Valve (Isolation valve)	Model: QSV-4, size= 4''	1
6	Backing and Roughing valves	Model: CV-25, 1" quarter swing butterfly valves.	2
7	Digital Pirani Gauge	Model: DHPG-222, Connection: KF16 flange type, Press. Range: $5x10^{-1}$ to $1x10^{-3}$ mbar.	2
8	Digital Penning Gauge	Model: DNPG-211, Connection:KF16 flange type, Press. 10^{-3} to 10^{-6} mbar.	1

4.2 Roots pumping system:-

List of components required:-

(i) Roots pump/roots blower

(ii) Vacuum chamber

(iii) Rotary pump

(iv) Pressure gauge

(v) Connecting pipes

(vi) Valves (needle valve and butterfly valve)

(vii) Capillary tube

(viii) Flow meter

(ix) Coupling and fittings

Table-7: Bills of material proposed for roots pumping system.

Sl. No	Details of components	Details of components	Qty
1	Roots pump/Roots blower	Displacement: 260 m^3/h at speed 960 rpm, 1.5 HP, 3 phase, Coupling: ISO 65 NB (N:B Capacity between 250 m^3/h to 280 m^3/h)	1
2	Rotary pump	16 m^3/h, 1440 rpm	1
3	Vacuum chamber	**20 Liter** capacity (L/D=1, Ports- 1xDN 100 ISO 65 NB Flange on bottom, 2x DN 16 ISO-KF and 1x DN 10 KF on top, 2x DN 25 KF on either side.), **Dimension 300L x 300D**	1
4	Pirani gauge with controller	1 mbar – 5 x 10^{-4} mbar, KF type.	1
5	Needle valve	SS, DN10 KF(for chamber venting)	1
6	Needle valve	DN25 KF, SS	1
7	Centering O-ring	DN25 KF, Viton	4
8	Centering O-ring	DN16 KF, Viton	2
	Centering O-ring	DN10 KF, Viton	1
9	Digital Flow meter,	Flow rate range: 0-4400 lpm	1
10	Flexible hoses	DN25KF,SS, 1 meter	1
11	Butterfly valve	4” size, ISO 65 NB	1
12	Hinged Aluminum Clamps	DN 25 KF	4
13	Hinged Aluminum Clamps	DN 16 KF	1
	Hinged Aluminum Clamps	DN 10 KF	1
14	Blank flange	DN 25KF, SS	1
15	Blank flange	DN 16KF, SS	1
16	Reducer or adapter	DN 100 65 NB –DN 25KF	1

4.3 Cryopumping system:-

List of components required:-

(i) Cryopump

(ii) Rotary pump

(iii) Compressor unit with connecting pipes

(iv) Vacuum chamber (20 liters)

(v) Pressure measuring devices (Pirani gauge and BAG)

(vi) Cold trap

(vii) Valves (roughing valve, backing valve, gate valve etc.).

(viii) Connecting pipes (like flexible hose etc.)

(ix) Coupling and fittings etc.

Table-8: Bills of material proposed for cryopumping system.

Sl. No.	Devices/Components (With descriptions)	Model No./Part No.	Qty	Sources/Contacts	Approx. Value INR(EUR)
1	Cryopump, COOLVAC 800,CL-V, DN 160 ISO-K	844160V0006	1	Oerlikon Leybold Vacuum	12,46,950.00 (14,670.00)
2	COOLVAC System Controller	844230	1	,,	1,82,070.00 (2,142.00)
3	COOLVAC Power Supply Compact	844135	1	,,	1,93,545.00 (2,277.00)
4	LAN-SC Cable, 10m	844261	1	,,	11,475.00 (135.00)
5	Cable PS-CP, 10 m	844129	1	,,	11,475.00 (135.00)
6	PS-SC Connection Cable; 1 m long	844141	1	,,	10,285 (121.00)
7	Cable PS-PM, 10 m	844128	1	,,	(162.00)
8	CP-COLDHEAD CABLE.4.5m	E400000323	1	,,	(115.00)
9	EL 4.5 Extension Cable Cold Head – Compressor	89374	1	,,	(157.00)
10	Compressor Unit: COOLPAK 2000 A, air cool,50Hz	840000V2010	1	,,	(11,043.00)
11	FL 4.5 (1/2", ½") Set, 4.5 m long	89287	1	,,	(1,431.00)
12	Rotary Pump 15 m^3/h, 250 l/m, 1440 rpm,ISO-KF25	ED15	1	Hind High Vacuum Company Pvt. Ltd	
13	BAG (Bayard-Alpert Gauge) Press. Range: 10^{-4} to 10^{-10}mbar	VT-BAG-01	1	VT Vacuum Techniques Pvt. Ltd.	
14	Cold trap	-		-	-

4.4 Vacuum Ejector pumping system:-

List of components required:-

(i) Vacuum Ejector pumps

(ii) Compressor with reservoir tank

(iii) Vacuum chamber.

(iv) Pressure measuring devices

(v) Condensers

(vi) Liquid ring pump

(vii) Valves

(viii) Flow meters

(ix) Capillary tubes (both glass and SS)

(x) Air dryer

(xi) Flat bottom test tube

(xii) Mercury etc.

Table-9: Bills of material proposed for ejector pumping system.

Sl. No	Name of components	Details of components	Qty
1	Ejector pump (2-stage) with condenser	2 inch	2
2	Liquid ring vacuum pump	70 m^3/h, 5HP, 1750 rpm, 2" inlet	1
3	Compressor (with pressure gauges)	Receiver tank: 30 litre, Operating press: 7 bar(100 Psi)	1
4	Glass tube (With 2/3rd of it should be calibrated in millimeter from either end)	5mm Outer Dia. X200mm length X 2mm thickness. ID tolerance:0.0025mm	5
5	Gate Valve	IN/OUT connection ports: 1 ½ NPTF	4
6	Nuts & Bolts (Mile steel)	ISO 65 NB	30
7	Nuts & Bolts (Mile steel)	ISO 50 NB	120
8	Pressure flow controller/Air pressure regulator valve/Flow control valve	Press. Range: 1 to 7 bar(kg/cm^2), Size: 1 ½ " NPTF	2
9	Pressure flow controller/Air pressure regulator valve/Flow control valve	Press. Range : 4 to 10 bar(kg/cm^2), Size: 1 ½ " NPTF	2
10	Air dryer (Inlet/Outlet filter)	Having connection 1 ½ NPT Female, Press. Range: 29" Hg to 10 bar(143 psi), Max. flow rate:180 cfm, dimension: 8 $\frac{1"}{4}$ x 5 $\frac{1"}{8}$	2
11	Flow meters	Range: 0-4500 lpm	2

12	Cylindrical chamber	**20 liters capacity** (L/D=1, Ports- 1xDN 100 ISO 65 NB Flange on bottom, 2x DN 16 ISO-KF and 1x DN 10 KF on top, 2x DN 25 KF on either side.) **Dimension 300L x 300D y**	2
13	Dial gauge	Range: 0.5 bar-30bar	5
14	Centering O-ring	DN16 KF, Viton	4
15	Centering O-ring	DN25 KF, Viton	3
16	Centering O-ring	DN40 KF, Viton	1
17	Hinged Aluminum Clamps	DN16 KF, SS	4
18	Hinged Aluminum Clamps	DN25 KF, SS	3
19	Hinged Aluminum Clamps	DN40 KF, SS	1
20	Blank flange	DN16 KF, SS	2
21	Blank flange	DN25 KF, SS	3
22	Blank flange	DN40 KF, SS	1
23	Capillary glass tube	OD=5mm, thickness=1.2mm, length=300mm	4
24	Flexible high pressure pipe	Connection port: 1 ½”	4

4.5 Calibration of Vacuum gauges:-

List of components required:-

(i) Rotary pump

(ii) Vacuum chamber

(iii) Pressure measuring devices(Pirani, Penning, Thermocouple and McLeod gauges)

(iv) Connecting pipes.

(v) Valves

(vi) Coupling and fittings etc.

Table-10: Bills of materials proposed for calibration of vacuum gauges.

Sl. No.	Components/Devices	Descriptions	Qty
1	McLeod Gauge	Model No.: MG-6, Pressure range-10 to 10^{-5} mbar	1
2	Thermocouple gauge with controller	0.1 mbar to10^{-2}mbar, DN 16 KF, SS	1
3	Glass-SS fittings	DN 16-DN10	2
4	Hinged Aluminum Clamps	DN 16 KF	1
5	Centering O-ring	DN 16 KF, Viton	1

4.6 Vacuum Insulation:

List of components required:-

(i) Main chamber (outer chamber)

(ii) Inner powder chamber (for powder vacuum insulation set-up only)

(iii) Flow meters

(iv) Water bath(Glass jar fitted with cork)

(v) Specimen, Lower guard and Upper guard

(vi) Perlite powder

(vii) MLI blanket

(viii) Thermocouple feed through

(ix) LN_2 container

(x) Valves

(xi) Liquid nitrogen

(xii) Condensate traps

(xiii) Stainless Steel pipes and SS flat plates (SS 316L, 10's) etc.

(xiv) Connecting pipes

(xv) Glass tubes

(xvi) Coupling and fittings etc.

Table-11: Bills of material proposed for vacuum insulation.

Sl. No	Name of components	Details of components	Qty
1	Cylindrical vacuum chamber (Main chamber)	**25 Liters** capacity, (Ports- 1xDN 25 ISO KF Flange on side, 3x DN 25 ISO-KF and 1x DN 16 KF on top) **Dimension 250Dia x 500Height**	3
2	Cylindrical vacuum chamber (Inner powder chamber)	**8 Liters** capacity, (Ports- 1xDN 25 ISO KF Flange on side, 3x DN 25 simple holes) **Dimension 150Dia x 463 Height**	1
3	Inlet condensate trap (Al, glass & Viton)	IN & OUT Ports: DN 25 KF-ISO/NW, Capacity: 1 litrs(approx.)	3
4	Thermocouple feed through with display unit	No. of pairs: 3, DN 16 KF, $1\frac{1}{8}$"-18 thread	2
5	Thermocouple temperature sensor	Temp. range: 77K to 600K	15
6	Squat style glass jar with cork stopper	Capacity: 700 ml	3
7	SS 316L,10's, Cylindrical Pipe	150mm dia.(OD) X 600mm Length(Nominal pipe size: 6")	3
8	SS 316L,10's, Cylindrical Pipe	250mm dia.(ID) X 700mm L (Nom. Pipe size 3 ½")	3
9	SS 316L, 15's, Round flat plate	Diameter 160 mm	4
10	SS 316L, 15's, Round flat plate	Diameter 530mm	2
11	Perlite Powder	10kg pockets	2

12	Wet type flow meter	2 lpm	2
13	Wet type flow meter	0.1 lpm (for MLI)	1
14	Adaptors (To connect glass & SS pipe)	25mm KF- 5mm UNR female (PTFE type)	5
15	Glass tube	5mm dia. (OD)x20cm length x 1mm thickness	5
16	Needle valve	DN25 KF, SS	3
17	Centering O-ring	DN25 KF, Viton	9
18	Centering O-ring	DN16 KF, Viton	1
19	Hinged Aluminum Clamps	DN 25 KF	9
20	Hinged Aluminum Clamps	DN 16 KF	1
21	Blank flange	DN 25KF, SS	3
22	Blank flange	DN 25KF, SS	3
23	Flexible Hose (SS) 1mtr	DN 25KF, SS	3
24	SS 316L,cylindrical pipe	OD=25mm, thickness 2.5mm, length=600mm	5

4.7 SOURCES/SUPPLIERS OF COMPONENTS:-

Some names of the companies which are the supplier or manufacturer of the above vacuum and non-vacuum components of the experimental set-ups.

Table-12: Manufacturers/Suppliers of vacuum components.

Sl. No	Name of company	Address of company & Contacts
1	Hind High Vacuum Company Pvt. Ltd.	No. 31,34 and 37, KIABD, Industrial Area, Dabaspet, Nelamangla Park Bangalore-562111, India Or 34 Kabir Road, Kolkata - 700 026, India Ph.: +91-9674646334 Email: shouvik@hhv.in Web site: www.hhv.in
2	VT Vacuum Techniques Pvt. Ltd.	36A-A.G.S Layout, MSR Nagar, Bangalore-560054 Or 2/13, 1st Stage, 1st Phase, Peenya Industrial Area, Bangalore - 560 058 Karnataka, India Ph.: +91 9845941264 Email: vacuumtech@vsnl.net, info@vtvacuumtech.com Web site: www.vtvacuumtech.com
3	Indian High Vacuum Pumps	Indian High Vacuum Pumps, B-28, 1st cross, 1st stage, Peenya industrial Estate, Bangalore-560058, India Ph.:+91 9448076807 Email: ihvp95@yahoo.in Web site: www.indianhighvacuumpumps.net
4	Pfeiffer Vacuum (India) Pvt. Ltd.	25/5 Nicholson Road, Secunderabad 500009, India Ph.: +91-40-27750014,+91 9391391544, Fax +91 40 27757774 Email: pvin@pfeiffer-vacuum.in Web site: www.pfeiffer-vacuum.net

5	Oerlikon Leybold Vacuum India	No. 82(P), 4th Phase, K.I.A.D.B. Plot Bommasandra Industrial Area Bangalore - 560 099, India Mob: +91 9342548183 Email:Haribabu.Muniramannagari@oerlikon.com Website:www.oerlikon.com
6	Hind Vactech Scientific Pvt. Ltd	155,Ground Floor, Chirag Delhi, New Delhi-110017 Mob: +91 9958822058,+91 9711805218 Email: info@hindvactechscientific.com peeyush@hindvactechscientific.com Vactechscientific@gmail.com
7	Everest Blower System	435, Modern Industrial Estate, Phase I, Bahadurgarh, Haryan-124507, India Mob: +91 9582600976 Email: north.ebs@everestblowers.com Web site: www.everestblowers.com
8	IVC Pumps Pvt. Ltd.	Plot No. 255, Phase-I, Near Devi masala, G.I.D.C. Estate, Naroda, Ahmedabad-382330, Gujarat, India. Tel. Ph.: +91 79 22807781/82, Mob: +91 9825708057, +91 9904707781 Email: ivc@ivcvacuumpumps.com Web: www.ivcvacuumpumps.com

Table-13: Manufacturers/Suppliers of non-vacuum components.

Sl. No	Name of company	Address of company
1	Apex Tubes Pvt. Ltd.	SCO-39, 2nd Floor, Sector - 31, Gurgaon, Haryana - 122 001, India Ph.: +91-124 - 4030 062, 4030 064 / 65 Email: apex@apextube.com Web: http://www.apextube.com
2	Gajjar Compressors Pvt. Ltd.	Plot No.5319, Phase IV, Opp.Ramol Police Chowkey, B/h.Windsor Ltd, G.I.D.C., Vatwa, Ahmedabad-382445. INDIA. (Gujarat, India) Phone : +91 79 25841400 / 25841700 / 32921948 Fax : +91 -79 -25841400 / 25841700 Mob:+91 9825039593, +91 9426051482 E-mail : info@aircompressorindia.com Web: http://aircompressorindia.com
3	Shree Siddhi Vinayak Industries	19 A, Plot No.19, Kashimira Industrial Estate, Behind Kashimira Police Station, Off Western Express Highway, Post - Mira, Dist. Thane - 401 104, Maharashtra, India. Mobile :+91 9867275620 Tel./Fax :+91-22-28457073 / 28458372 Email: response@minivacpumps.com Web: http://www.minivacpumps.com
4	Cole-Parmer India Pvt. Ltd	403–404, B-Wing, Delphi Hiranandani Business Park, Powai Mumbai-400 076, India Phone: 91-22-6716-2222 Fax: 91-22-6716-2211 E-Mail: info@coleparmer.in Web: http://www.coleparmer.com
5	Neha Metal And Alloys	Mr. Rajesh Bhansali (General Manager). No. 104, 82-84-86, Millennium Building, C. P. Tank Road Mumbai - 400004, Maharashtra, India Ph.:+(91)-(22)-66595865, +(91) 8373902698, +(91)-(22)-66595865 Email: nehametalandalloys@gmail.com Web: http://www.steelpipe.co.in

6	Naugra Export	6148/6, Guru Nanak Marg, Ambala Cantt, Haryana, India. Ph.: +91-0171-2643080, +91-0171-2601773, +91-0171-4006655 Email : sales@naugraexport.com Website: www.naugraexport.com
7	Dwyer Instruments Inc.	102 Indiana Hwy. 212 (P.O. Box 373), Michigan City, IN 46360 (46361) USA. Ph.:219/879-8000, 1-800-872-9141 Fax:219/872-9057 Email: https://www.dwyer-inst.com
8	Sierra Instruments	5 Harris Court, Building. L Monterey, CA-93940 Fax: 831-373-4402 Or Second Floor Building 5, Senpu Industrial Park 25 Hangdu Road Hangtou Town Pu Dong New District Shanghai, P.R. China 201316 Phone: 8621 5879 8521/22 Fax: 8621 5879 8586 Web: http://www.sierrainstruments.com

CHAPTER-05

EXPERIMENTS DONE

Out of six experiments I am able to do one experiment complete in *NIT Rourkela*.

The experimental set-up done is the diffusion pumping system. But I have done some other experiments in the *Dept. of Cryogenics Engineering*, *IIT Kharagpur.*

The experiments were:

(i) Calibration of secondary vacuum gauges by primary gauge (i.e. Capacitance gauge).

(ii) Conductance measurements.

(iii) Vacuum generation by sorption pump.

(iv) Study and pumping speed measurement of rotary pump and

(v) Study of turbo-molecular pumps (Vacuum generation only).

The figure of diffusion pumping system/vacuum pumping system which is installed in Vacuum Laboratory, Dept. Mechanical Engg., NIT Rourkela is given in **Fig-18**.

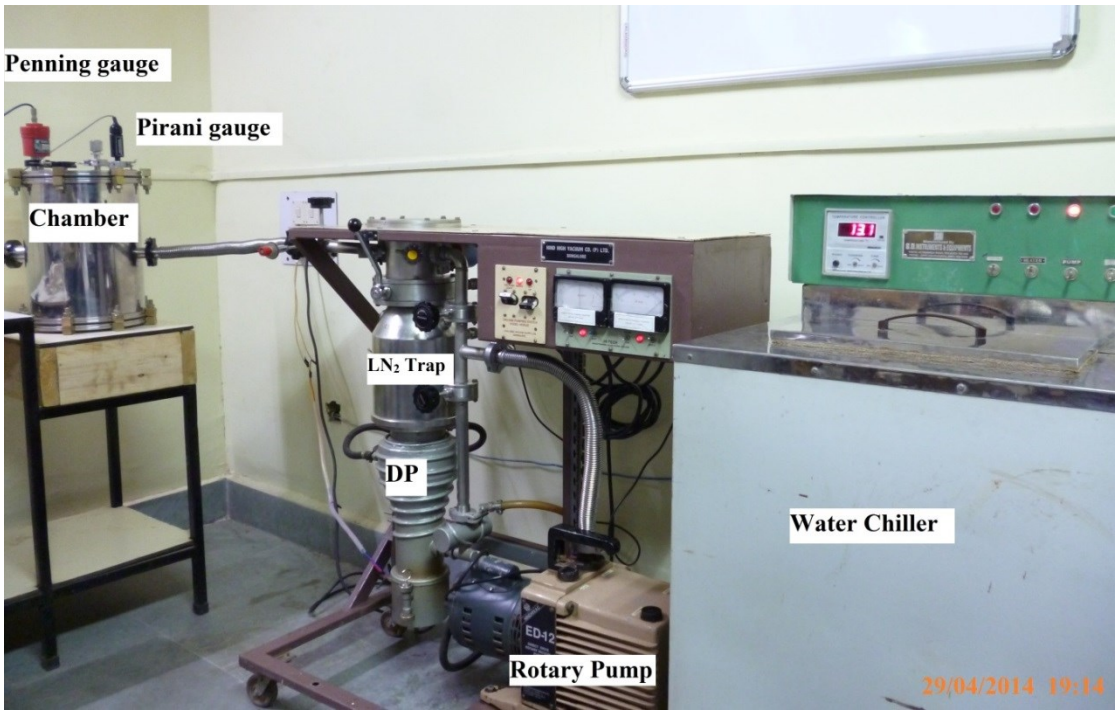


Fig-18, Diffusion pumping system at NIT Rourkela

The experiments for diffusion pumping system was carried out and due to too much leak rate, vacuum achieved was quite low. It was about $4x10^{-04}$mbar (Without filling LN_2 in LN_2 trap). And with filling LN_2 in LN_2 traps, it was generated upto $1x10^{-04}$mbar. But it should be order of 10^{-6}mbar.

CHAPTER-06

Cryogenics and Vacuum Technology: Future Work and Scope

We have to work quite hard to get lowest pressures and also very low temperature.

Understand the limitations of

- Outgassing
- degassing
- Pumping
- Careful design and operation of vacuum systems
- Performance (specification).
- Economics considerations and
- Vacuum's boundary conditions.

For most purposes vacuum is just a tool. Most users would prefer not to have to bother with it. The accelerator physicists who determine the properties of the next generation of machines would like the vacuum engineer to design a vacuum system where-

- The pressure is zero
- The vacuum pumps and gauges take up no space
- The cost is trivial.

The performance of vacuum insulation will continue to improve as better core materials, barrier films and technology develops. The main focus is:

1. Minimizing of thermal transfer processes

It is well known that the material property concerning thermal transport is quantified by its thermal conductivity λ according to the actual temperature gradient. This value λ in turn represents accumulation of single values, which each for each other describes a certain way of thermal transfer:

a) Thermal conduction within the material pores (gas conduction) $\lambda_{L,G}$

b) Thermal conduction within the solid structure (solid conduction) $\lambda_{L,F}$

c) Radiation transfer between the pore's surfaces λ_S

d) Convection within the pores λ_K

2. Improvement in the following factors:

a) Vacuum Insulating Sandwich (VIS)

b) Vacuum Isolation Panels (VIP)

c) The Capability of Vacuum Insulation in Comparison

d) Lifetime

e) VIS Elements

f) VIP-Elements

g) Mechanical Load Capacity

CHAPTER-07

SUMMARY:-

Design and Modelling of Vacuum Experimental set-ups

Mr. Trilochan Penthia, Supervisor: Prof. Sunil Kumar Sarangi
Roll No.: 212me5328, Cryogenics and Vacuum Technology
National Institute of Technology, Rourkela-769008, Odisha, India
Email:trilochankoraput@gmail.com.

Abstract:

This thesis deals with study, modelling and designing of some laboratory apparatus in Cryogenics Engineering and Vacuum Technology field. The project is totally educational oriented. Project's aim is to give a clear idea about vacuum technology and modelling of such vacuum experimental set-ups which can serve as the laboratory experiments for both undergraduate and post graduate students.

This project work is broadly classified into three parts:--

(i) Study, selection techniques and designing of some vacuum components.
(ii) Modelling and operation of vacuum experimental set-ups.
(iii) Making bills of materials for the proposed experimental se-ups.

Introduction:

This project works focused mainly on generation of vacuum of different levels and reduce the heater transfer phenomena of cryogenics system (i.e. by vacuum insulations). Different vacuum level means like low vacuum (1000mbar to 1 mbar), medium vacuum (1 mbar to 10^{-03}mbar), high vacuum (10^{-03}mbar to 10^{-07}mbar) and ultrahigh vacuum (more than 10^{-07}mbar).

For any vacuum system, vacuum pumps are unavoidable and main parts of the system.

There are different vacuum pumps having different pumping speed are available in market.

The names of some vacuum pumps are namely;

(viii) Rotary pump(Ultimate pressure: upto $1x10^{-03}$mbar)

(ix) Diffusion pump(upto $1x10^{-06}$mbar)

(x) Roots pump/roots blower(upto $1x10^{-04}$mbar*)

(xi) Cryopump(upto $1x10^{-12}$mbar)

(xii) Ejector pump(upto 50 mbar)

(xiii) Turbomolecular pump (upto $1x10^{-09}$mbar) and

(xiv) Sorption pump (upto $1x10^{-04}$mbar*) etc.

The tasks of this project related to experimental set-ups of vacuum pumps are as follows:

- Study, design and modelling of experimental set-ups..
- Generation of vacuum.
- Pressure of measurement w.r.t time.
- Calculation pumping speed of pumps and Plotting graphs between pumping speed (S), flow rate (Q), pressure (P), time (t) etc. (like P vs t, S vs P etc.).

Experimental set-ups:-

Following six experiments are proposed.

Experiment-01: Study of diffusion pumping system and measurement of pumping speed.

Experiment-02: Study & Calculation of pumping speed of roots pump.

Experiments-03: Study & Calculation of pumping speed of vacuum ejector pump.

Experiments-04: Study & Calculation of pumping speed of cryopump.

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Experiments-05: Calibration of vacuum gauges using primary gauges**.**

Experiments-06: Study, calculation of boil-off rate and heat transfer characteristics of vacuum insulations.

N: B Methods used for calculation of pumping speed of pumps:

(i) Constant volume method.

(ii) Constant pressure method.

Conclusion:-

The design of vacuum chambers and modelling of experimental set-ups were done for a vacuum laboratory. Different vacuum pumps, pressure measuring devices and other vacuum components were studied. The proposed experiments are maintained theoretically rather than practical. This project is educational oriented. Both UG and PG student can do their laboratory work as well as research work in the proposed "Vacuum Technology Laboratory".

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